Hager-Rambo Flood Control Facilities Study Report

Downtown and Burlington GO Mobility Hub
Burlington, Ontario
Project TPB198130

Prepared for:

City of Burlington
426 Brant Street, Burlington, ON L7R 3Z6

9/22/2020

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1.0 Introduction

The City of Burlington is undertaking a land use planning study for four (4) Mobility Hub areas across the City. These are areas as located around the City's GO stations including Appleby GO, Burlington GO, Aldershot GO, and also includes the Downtown area, where re-development and intensification are expected. In support of this planning effort (originally lead by Brook McIlroy Inc for the GO Station Mobility Hubs and SGL Planning for the updated process for the Downtown), Dillon Consulting Limited (Dillon) prepared a series of Scoped Environmental Impact Studies (EIS) for each of the four (4) mobility hubs. The purpose of the Scoped EISs was to document existing environmental conditions, and assess potential environmental impacts and mitigation strategies related to the expected development in these areas.

In support of this effort, Wood Environment & Infrastructure Solutions (Wood) prepared a series of flood hazard and scoped stormwater management assessments for each of the three (3) mobility hubs and the Downtown area. These documents define existing flood hazards for areas of anticipated development/redvelopment, and also provide preliminary/functional stormwater management strategies, based on locally available drainage infrastructure and associated service capacity. A combined report (ref. "Flood Hazard and Scoped Stormwater Management Assessment", Wood, January 2020) was prepared for the Burlington GO Mobility Hub and Downtown areas. The limits of this study area is presented in Drawing 1 (attached).

As part of the execution of the flood hazard studies cited above, it became apparent that in order to clearly define and support the flood risk mapping for the respective Mobility Hubs in the Burlington and Downtown areas, the function of the major legacy flood control structures at Freeman, East Rambo and West Hager (ref. Drawing 1), needed to be validated and supported. These legacy flood control structures, constructed at the time of implementation of the then Hwy 403 (now Hwy 407), in the 1990's, were a joint undertaking between the City, Province (MTO and MNR) and Conservation Halton (CH). The subject Highway through Burlington is a largely depressed facility which cut-off drainage for the Hager-Rambo headwaters resulting in the need for a significant diversion and associated flood storage. These structures provide flood control for major storms (100 year to Regional Storm), and planning for downstream development has accounted for the attenuative function of these facilities since their construction in the 1990's.

CH has requested that in order to support crediting the flood control function of the existing facilities within the subject study area (i.e. the East Rambo Flood Control Facility, the West Hager Flood Control Facility, and the Freeman Pond), a specific focused study be undertaken to assess the structural stability and functional condition of these facilities. The scope of this study includes:

- Visual Inspection by Professional Engineers
- Structural Stability Assessment (Structural Engineering)
- Geotechnical Stability Assessment (Geotechnical Engineering)
- Facility Capacity and Performance Verification (including topographic survey verification)
- Sensitivity Analysis (primarily focused on Climate Change Considerations, however the approach also considers other uncertainties related to hydrology and hydraulics)
- Remedial Works and Implementation Considerations

This report is intended to document the outcomes of the preceding analyses, with the intent of providing sufficient details and related justification to allow CH to support crediting the flood control function of the three (3) facilities accordingly.

2.0 Visual Inspections - Functional Assessment and Structural Culvert Assessment

2.1 Background and Approach

Over the course of the flood risk assessment for the respective mobility hubs, the City of Burlington (City) consulted with Conservation Halton (CH) to develop a scope of visual inspections/assessments of the legacy flood control facilities (Freeman, East Rambo and West Hager – refer to Drawing 1). The visual inspection program was conducted over a series of visits by a combination of City staff and Wood staff from water resources engineering, geotechnical engineering and structural engineering disciplines. The purpose of the visual inspections has been to consider both functional issues (refer to Section 2.2) and structural issues (refer to Section 2.3). The inspections have been intended to document possible erosion (channel or slope), sediment build-up, animal activity, excess vegetation, evidence of hydraulic functional issues, and to visually assess the structural condition of the respective facility outlet control structures. The geotechnical stability assessment (including visual inspection with a focus on slope stability) is documented in Section 3.0, which has examined slope stability matters related to the flood control facilities' containment systems.

Furthermore, in discussion with CH and the City, it was also recognized that the anecdotal evidence of the lack of significant sediment build-up and absence of any significant blockages at the facility outlets were important observations to document, as this legacy of performance over the past two decades further supports the interest of the City in crediting the FCF's function in downstream regulation.

2.2 Visual Inspections – Functional Assessment

2.2.1 East Rambo Flood Control Facility

A visual inspection of the East Rambo Flood Control Facility (FCF) was undertaken on March 11, 2020 to assess functional considerations. Overall, the East Rambo Flood Control Facility appears to be functioning as designed, with no significant hydraulic functional issues. A detailed summary of the components reviewed in the field by Wood's Senior Water Resources engineer follows. Refer to Drawing 2 (attached) for an overview of the East Rambo FCF.

<u>Inlets</u>

There are four (4) primary inlets: two (2) at the east end receiving local runoff from the North Service Road, and external runoff from Roseland Creek; one (1) at the mid-point, receiving runoff from the East Rambo Creek subcatchments north of the CNR, and the main inlet at the west limit, receiving runoff from the main branch of East Rambo Creek. There is an internal twin CSP inlet under the maintenance access road in the west end, connecting the main creek from the CNR crossing to the main facility. There is also a twin CSP culvert under the maintenance access road in the eastern end of the facility, which connects the easterly cell with the main cell (ref. Photos ER.3, 6, 7, 8, & 11).

All inlets appear to be functioning as intended, with the exception of the middle inlet culvert from the north. There is erosion and scouring at the point where the subject culvert discharges into the flood control facility, which would require repair. Topographic survey is also required to determine if the upstream end of the CSP has become exposed with loss of cover, and whether it has lifted (ref. Photo ER.6).

The main creek channel at the west end of the facility, which runs between the CNR culvert and the twin CSP is stabilized with armour stone on the south side and there is only minor erosion observed at the entrance to the CSPs. There is also evidence of debris cleaning/removal from the upstream side of the culverts. The armour stones are all level and there are no portions of the wall leaning into the creek. However, given the potential for scour, the armour stone bank should be regularly inspected. The City has observed severe erosion immediately upstream of the CNR crossing, where the creek has historically been making two ninety-degree bends. There is also evidence of erosion on this creek upstream of the CNR to the next road crossing (Industrial Drive), which is considered indicative of the high velocity flows which this creek exhibits.

There is one (1) inlet ditch from the North Service Road which has had the rip-rap lining become eroded and moved to the creek invert, which should also be repaired (ref. Photo ER, 12).

Outlet

There is a single concrete box culvert outlet which is discussed and assessed further in Section 2.3 (ref. Photo ER.9), which appears to be performing as per design, provided that any debris is regularly removed from the grate. There is evidence of repeated maintenance to remove debris from the grate, and some temporary piles of debris which should be removed.

Based on discussion with City staff, this outlet is inspected regularly for debris, which is removed as required. There were no other observed locations of debris accumulation or blockage in the facility, and the other culverts were clear. The outlet grate was only partially blocked by debris (ref Photos ER.9 and ER.14). Further as cited earlier, based on anecdotal evidence of performance over the past two decades, there have been no reports of adverse blockages or significant sediment build-up.

Channels

Given the number of inlets and cells, the facility also has several internal small channels. These connecting channels appear to be functioning as intended. There are no signs of any significant erosion in the channels (ref. Photos ER.3, 4, 5, 10, 11).

Side Slopes and Vegetation

All of the facility side slopes are densely vegetated with grass and woody vegetation, that being mostly sumac (ref. Photos ER.1, 2, 5, & 11). There is no signs of erosion on the side slopes. There is only one (1) observed sign of small mammal burrowing in the side slope. There are deer trails along a number of the side slopes. The woody vegetation is comprised mostly of shrubs, and there are a number of smaller trees on the north side slope (ref. Photo ER.5). There are some trees on the south side slope (road embankment). In the vicinity of the hydro towers, the vegetation is being cut/maintained by Hydro, and all of the woody vegetation is cut.

There is rip rap placed on the north side slope, at the west end cell, to protect against potential erosion of the sides, should the main channel into the facility become blocked with debris, and the inflow channel spill over the bank and across the maintenance access.

Vegetation pockets are noted within the main cell of the pond itself, which may indicate sedimentation and the need for a clean-out. A bathymetric survey of the pond would be required to confirm this definitively.

Outlet Control Berm and Spillway

The MTO North Service Road embankment forms containment on the south side of the facility. There is no formal or defined outlet control berm. Based on an understanding of this FCF's operation, the facility would potentially spill westerly along the CNR corridor, through the CNR QEW underpass under initial conditions which exceed the design capacity of the facility, and at sufficiently high water levels, ultimately spill southerly towards and over the North Service Road. There is no formal outlet control spillway for the East Rambo Flood Control Facility to either location.

Photo ER.1: East Rambo FCF east cell

Photo ER.2: East Rambo FCF typical slope vegetation

Photo ER.3: East Rambo FCF driveway culvert between east and main facility

Photo ER.4: East Rambo FCF channel inlet from north – limited erosion

Photo ER.5: East Rambo FCF looking west

Photo ER.6: East Rambo FCF inlet from north, note scour repair required

Photo ER.7: East Rambo FCF u/s end of twin inlet culverts to main Facility at west end

Photo ER.8: East Rambo FCF d/s end of twin inlet culverts to main Facility at west end

Photo ER.9: East Rambo Facility outlet control culvert with safety grate and debris

Photo ER.10: creek u/s of East Rambo FCF inlet in west corner – minimal scouring

Photo ER.11: East Rambo creek d/s of CNR at west end of FCF

Photo ER.12: East Rambo FCF rip rap spillway eroded at North Service Road ditch near entrance

2.2.2 Freeman Flood Control Facility

A visual inspection of the Freeman Flood Control Facility (FCF) was undertaken on December 5, 2019 to assess functional considerations. Overall, the Freeman Flood Control Facility appears to be functioning as designed, with no significant hydraulic functional issues. A detailed summary of the components of the facility reviewed in the field by Wood's Senior Water Resources engineer follows. Refer to Drawing 3 (attached) for an overview of the Freeman FCF.

Inlets

There are two (2) primary inlets to the Freeman FCF: one (1) central inlet receiving the main East Hager Creek constituting the primary diversion flow from the highway, and one (1) storm sewer inlet at the east end which receives runoff from the local East Hager subcatchment immediately north of the QEW and west of Brant Street (ref. Photo F.6 for main inlet). All inlets appear to be functioning as intended. Note that there is also a wetland constructed as a retrofit in the east end of the facility, to provide water quality treatment for the runoff from the incoming storm sewer which services the retail Brant Plaza to the north.

Outlet

There is a single concrete box culvert outlet and embankment which is discussed/assessed further in Section 2.3 (ref. Photo F.2), which appears to be performing as per design, and there is no evidence of any erosion or debris blockage. There were no other observed locations of debris accumulation in the facility, and the inlet culvert was also clear of any debris. Based on discussion with City staff, there have not been any historic incidents of debris accumulation in this facility over the past two decades.

Channels

There are two connecting channels in the facility: one from the main inlet to the outlet, and a second channel from the east storm inlet and wetland westerly to the main channel. These both appear to be functioning as intended. There are no signs of any significant erosion in the channels (ref. Photos F.4, 5, & 6). There is concrete block lining in most of the channel, and there is no evidence of any notable damage to the concrete block lining. There are shrubs and trees growing along the channel (ref. Photos F.4 & 5) which should be monitored to ensure that the roots do not negatively impact the channel. The roots may be providing some degree of stabilization.

Side Slopes and Vegetation

All of the facility side slopes are densely vegetated with grass and some woody vegetation (ref. Photos F.1, 2, 3, & 7-10). There are no signs of erosion on the side slopes. The woody vegetation is comprised mostly of shrubs, however there are a number of trees throughout the facility, and additional trees located in the water quality cell in the east end of the facility. None of the trees appear to be having any negative effect on the slopes. In the vicinity of the hydro towers, the vegetation is cut/maintained by Hydro, and all of the woody vegetation is currently cut.

Outlet Control Berm and Spillway

The outlet control berm is well vegetated (ref. Photo F.1) and does not have any evidence of erosion. The upstream face has woody vegetation (ref. Photos F.2 & 3). The spillway is stabilized with interlocking concrete block which is covered with topsoil and vegetation.

Photo F.1: Freeman FCF Outlet Berm

Photo F.2: Upstream end of Freeman FCF Outlet Control Culvert

Photo F.3: Upstream face of Freeman FCF Outlet Berm

Photo F.4: Lined channel in lower section of Freeman FCF

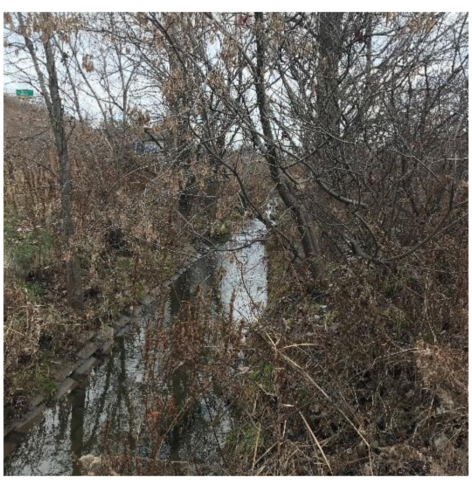

Photo F.5: Lined channel in lower section, near inlet, note woody vegetation

Photo F.6: Downstream end of main inlet culvert under QEW/403

Photo F.7: Freeman FCF – typical treed slopes

Photo F.8: Upper east end of Freeman FCF

Photo F.9: Freeman FCF – vegetated slopes

Photo F.10: South facing outer slopes on the Freeman FCF

2.2.3 West Hager Flood Control Facility

A visual inspection of the West Hager Flood Control Facility (FCF) was undertaken on December 5, 2019 to assess functional considerations. Overall, the West Hager Flood Control Facility appears to be functioning as designed, with no significant hydraulic functional issues. A detailed summary of the components of the facility reviewed in the field by Wood's Senior Water Resources engineer follows. Refer to Drawing 4 (attached) for an overview of the West Hager FCF.

<u>Inlets</u>

There are two primary inlets, the west and east tributary of the West Hager Creek (ref. Photos WH.5 & 6). Both inlets appear to be functioning as intended hydraulically, however there is evidence of erosion and recent City works (ref. comments under "Channels").

<u>Outlet</u>

There is a single concrete box culvert outlet which is discussed/assessed further in Section 2.3 (ref. Photos WH.9 & 10), which appears to be performing as per design, with no evidence of any debris blockage.

Notwithstanding, bedload and sediment filling of the box appears to have occurred over time, such that the effective opening height ranges between 0.8 and 0.9 m (1.1 m reported height in the City's GIS database). Of note, the available record drawings (refer to Appendix A) indicate a 1.44 m x 1.44 m box culvert which suggests the dimensions may have been altered a later date (given the field measured 1.8 m width). The sedimentation should be removed such that the full capacity of the outlet culvert is restored. There were no other observed locations of debris accumulation elsewhere in the facility. Based on discussion with City staff, there have not been any historic incidents of debris accumulation in this facility over the past two decades.

Channels

The main channel and tributaries within the most downstream portion of the facility all appear to be functioning hydraulically as intended. The upper west tributary appears to have been recently realigned by the City, to mitigate local valley slope erosion and to repair a recent slope failure on the east valley slope (ref. Photo WH.5). This work appears to have been completed within the past year and would therefore likely still be under warranty and observation by the City.

There are signs of typical bank erosion on the upper east tributary, which should be monitored for potential impact on local vegetation. There are no valley slopes currently impacted on the east tributary (ref. Photo WH.6).

Downstream of the flood control facility, there is an armour stone-lined channel. There are signs of erosion and scour which may potentially impact the adjacent lands but should not impact the function of the flood control facility (ref. Photo WH.7). The armour stones immediately downstream of the facility box culvert should be inspected regularly for undermining, and may require some stabilization (ref. Photo WH.8).

Within the facility, there are many shrubs and trees, including those growing along the channel (ref. Photo WH.4) which should be monitored to ensure that the roots do not negatively impact the channel. The roots may be providing some degree of stabilization.

Side Slopes and Vegetation

All of the facility side slopes are densely vegetated with grass and woody vegetation (ref. Photos WH. 3 & 4). There are no signs of erosion on the side slopes. The woody vegetation is comprised mostly of trees. None of the trees appear to be having any negative effect on the slopes.

Outlet Control Berm and Spillway

The outlet control berm is well vegetated (ref. Photos WH.1, 2 & 3) and does not have any evidence of erosion on either the upstream or downstream face. Both the upstream and downstream sides of the berm have some woody vegetation. The spillway is formed by the earthen berm, and spans the width of the valley, with an increased grade at the tie-ins at the sides. There is no evidence of erosion of the berm/spillway and stabilization measures appear to be in good condition.

Photo WH.1: West Hager FCF downstream face of outlet control berm

Photo WH.2: West Hager FCF downstream face of outlet control berm

Photo WH.3: West Hager FCF upstream face of outlet control berm

Photo WH.4: Looking north in main cell of West Hager FCF

Photo WH.5: Upper west tributary to West Hager FCF – note recent City valley erosion repairs

Photo WH.6: Upper east tributary to West Hager FCF – typical bank erosion scar

Photo WH.7: West Hager FCF downstream of facility outlet – note erosion

Photo WH.8: Immediately downstream of outlet culvert – armour stones potentially undermining

Photo WH.9: Downstream face of outlet control culvert, note sediment deposition mid-depth

Photo WH.10: Channel immediately upstream of outlet control culvert, minor erosion, deposition in culvert

2.3 Visual Inspection - Structural Culvert Assessments

The facility outlet control culverts have been assessed to determine their structural and functional condition. Visual inspections for structural condition were completed on February 21, 2020. It should be noted that detailed structural evaluations of these culverts have not been performed hence Wood can only comment on the structural *condition* of the culverts rather than their structural *capacity*. The purpose of the structural culvert condition assessments is to identify any structural and functional defects observed through visual site inspections and provide a professional opinion on the criticality of these defects with regards to the overall performance of these flood control facility outlets.

2.3.1 East Rambo Flood Control Facility

The East Rambo flood control facility (FCF) is located north of the North Service Road between Brant Street and Guelph Line (refer to Drawing 2). The facility outlets into a concrete box culvert (3.0 m wide x 1.5 m high) with a curved steel grate cover at the southwest corner of the site. This concrete culvert inlet (FCF outlet) is shown in Photo ER.14.

For the site investigation, the culvert face was not accessible from the upstream inlet (FCF outlet) end due to the curved steel grate cover being bolted to the culvert inlet. Further, for the site investigation the downstream outlet end of the culvert could also not be located or inspected. Since Wood staff was unable to walk through the culvert and observe the condition of the barrel and outlet of this structure, this assessment is inherently limited to the structural and functional defects observed at the inlet (FCF outlet) end of the culvert and Wood is hence unable at this time to provide a professional opinion with regards to the condition of the balance of the culvert structure. Given that this system is part of MTO's infrastructure for the QEW/Hwy 403 it may be prudent to contact MTO for any more recent or detailed condition surveys related to this culvert.

It is understood that the culvert structure extends to the downstream side of the QEW (Queensway Drive) and outlets to the downstream portion of East Rambo Creek (refer to Drawing 3; 250 m approximate length) and the outlet end of the culvert is fenced to prevent public access. Therefore, if an inspection of the entire culvert is required in the future, Wood will require MTO access to the outlet end of the culvert and this inspection would require confined space entry precautions.

As part of the site investigation, the visible portions of the culvert inlet appeared to be in overall good condition with areas of light scaling, pop-outs and light spalling. These pop-outs and spalls were likely created during the fabrication and installation of this concrete culvert, as they are localized and do not have areas of delamination around the spalled concrete.

The base of the steel grate cover could not be inspected due to a large build-up of vegetation and debris. Visible sections of the steel grate cover appeared to be in good condition with no observed areas of section loss or deformation. The galvanized coating along the steel grate appeared to be in overall fair to good condition with areas of deteriorated galvanized coating along the base of the steel grate cover. The base slab at the culvert inlet, extending to the end of the culvert wingwalls, was observed to be in good condition with no observable scouring concerns. The base slab in front of the culvert inlet (FCF outlet) provides protection to the main culvert structure from scouring effects, therefore scouring is not expected to be of concern in the long term.

The embankments surfaces directly beside the culvert inlet are a mixture of sediment, vegetation and rip rap with no observable erosion concerns. These embankments are retained by concrete wingwalls extending on a skew from the culvert inlet. These wingwalls provide protection to the adjacent embankments from abrasive flows and erosion. Beyond the existing wingwalls are earthen embankments covered with vegetation. While these embankments have no hard protection from abrasive flows they are covered with well-established vegetation along the base of the embankments. The upstream face would not be expected to experience fast moving abrasive flows as it would be in the ponded zone.

Overall, this flood control facility outlet appears to be in good condition. In conclusion, the East Rambo FCF outlet at this time would only require minor maintenance to ensure the outlet is fully functional during a major storm event. The caveat though to this conclusion relates to the uncertainty associated with the balance of the culvert which was not able to be inspected as part of this scope.

Photo ER.13: East Rambo FCF

Photo ER.14: East Rambo FCF Outlet,

2.3.2 Freeman Flood Control Facility

The Freeman flood control facility (FCF) is located south of the Queen Elizabeth Way, west of Brant Street (refer to Drawing 3). The FCF outlets into what appears to be a cast-in-place rigid frame concrete culvert with a concrete liner along the base of the culvert located at the southwest corner of the FCF. Overflow from the Freeman FCF drains through the culvert and outlets into a concrete channel south of the facility. The cast-in-place concrete culvert is shown in Photo F.12

As part of the site investigation, the FCF outlet was accessed from the downstream end of the culvert and Wood's site inspectors walked through the culvert barrel to the upstream end of the culvert. Based on this field review, the culvert structure appeared to be in overall good condition with small spalls, light to medium scaling, minor segregation of the concrete, primarily below the high-water level, a few cracks (varying from narrow to wide) and stalactites. These defects are depicted in the photos which follow. Overall, the defects observed throughout the culvert did not appear to be critical and there was nothing apparent during the structural investigations that would lead Wood's engineers to consider the culvert would have reduced structural capacity. Further, no debris or other obstructions were observed through the culvert structure that would limit the hydraulic capacity of the culvert during a major storm event.

Beyond the inlet and outlet ends of the culvert are concrete channels that provide the adjacent embankments protection from abrasive flows. Based on the site investigation, Wood staff observed no signs of erosion along the embankments above the concrete channels. As stated previously, the culvert is lined with concrete and contains concrete seats through the culvert barrel, presumably for inspection access. In conventional open footing culverts with concrete seats, scouring is a critical concern because the bases of the concrete seats have no protection from abrasive flows. In this case however, the concrete liner prevents water from forcefully removing soil from under the concrete seats. Therefore, Wood does not consider flow scouring to be a potential concern along the culvert.

Photo F.11: Freeman FCF

Photo F.12: Upstream end of Freeman FCF Outlet Control Culvert

Photo F.13: Downstream end of Freeman FCF Outlet

Photo F.14: Barrel View Looking North u/s Towards Culvert Inlet

Photo F.15: Typical Condition of Barrel Soffit

Photo F.16: Medium to Wide Cracking at Culvert Outlet

Photo F.17: Segregation of Concrete Below High-Water Level

Photo F.18: Stalactites Along Barrel Soffit and Culvert Walls

Photo F.19: Localized Spalling with Exposed Rebar at Culvert Wall

2.3.3 West Hager Flood Control Facility

The West Hager flood control facility (FCF) is located north of the North Service Road between Skyview Drive and Kerns Road (refer to Drawing 4). Overflow from the West Hager FCF outlets into a precast concrete box culvert that drains the water through to the continuation of West Hager Creek on the north side of the

North Service Road. The inlet and outlet ends of the culvert contain two concrete retaining walls on either side of the inlet to retain the sloped soil overtop of the culvert structure.

Due to the limited clearance provided by the culvert and the frozen water through the culvert at the time of inspection, the site inspectors were unable to access the barrel of the culvert. Therefore, site inspection of this culvert structure only consisted of the inlet and outlet ends and the visible portions of the barrel that could be viewed from these ends.

Upon site investigation, the existing precast concrete culvert structure appeared to be in overall good condition with light cracking and scaling seen throughout with minimal differential settlement observed between the precast concrete units near the inlet and outlet ends. Gaps between the precast units, with frozen water draining between the gaps, was observed. Drainage through the precast units can be caused by defects in the waterproofing, or a lack of waterproofing above the precast units. Drainage between the precast units can over time drain away earth from above the precast units causing the earth above the culvert to settle, however the level of drainage observed between the units did not appear to be of concern at this time.

The earth and vegetation embankments adjacent to the inlet end of the culvert are retained by concrete wingwalls extending on a skew from the culvert inlet. The earth embankments beyond the concrete wingwalls are heavily vegetated and this vegetation would provide increased stability along the embankments. Based on the site investigation Wood staff identified no erosion concerns along these embankments. The downstream (outlet) end of the culvert contains an armourstone retaining wall along the southeast side of the creek that supports the sloped soil on the southeast downstream end of the West Hager FCF. Based on the site investigation the armourstone units appeared to be embedded to a sufficient depth into the creek bed to prevent scouring under the armourstone wall during high flow events. The southwest embankment across from the armourstone retaining wall contained sediment and light vegetation. Upon site investigation this embankment was noted to be eroding with medium severity. Since this embankment does not have any hard protection from abrasive flows, continued erosion along this embankment may be a concern in the future if left unprotected. Notwithstanding, this would not be expected to impact the performance of the FCF directly.

Due to the level of sediment build-up at the upstream and downstream ends of the culvert, the base of the culvert could not be inspected. This level of sediment build-up would provide the foundation material along the culvert with a nominal amount of protection from scouring effects. Standard box culvert details include a concrete toe wall at the upstream and downstream ends of the culvert to protect the culvert from scouring effects therefore, it is likely that the upstream and downstream ends of the culvert contain supplementary scour protection. However, additional investigations or as-built drawings would be required to confirm this definitively.

From the portion that could be inspected, this FCF outlet appears to be in good condition with no clear structural defects observed through the culvert that would reduce the structural capacity of the culvert. If a full inspection of the entire culvert barrel is required, Wood will need to return at a time when the water is lower and not frozen, and this inspection would require confined space entry precautions.

Photo WH.11: West Hager FCF

Photo WH.12: West Hager FCF Outlet Culvert

Photo WH.13: West Hager Culvert Outlet (Downstream Side)

Photo WH.14: Barrel View Looking North Towards Culvert Inlet, Note Drainage Through Joints

Photo WH.15: Barrel View Looking South Towards Outlet, Note Drainage Through Joints

2.4 Conclusions and Recommendations

Facility Visual and Functional Assessment

Based on Wood's visual and functional assessment of the three (3) Flood Control Facilities (FCFs) no critical functional issues were evident; all three (3) FCFs appeared to be generally in good working order. Notwithstanding, the following items have been noted which warrant follow-up activities/works:

- East Rambo FCF
  - Erosion repair at mid-point inlet into pond, including topographic survey verification and mitigation of culvert scour and culvert perching
  - Repair to rip rap lining of inlet ditch from North Service Road
  - Removal of debris from outlet grate and structure
  - Consideration for a bathymetric survey of the pond to confirm sedimentation and vegetation accumulation and need for a potential clean-out
- West Hager FCF
  - Remove sedimentation in outlet control culvert

Structural Culvert Assessment

Based on Wood's structural visual site investigation of the Freeman and West Hager FCF, it is Wood's professional opinion that the facility control structures at the FCF outlets do not have critical defects that would lead Wood to consider the respective structures would have reduced structural capacity during a major storm event. Further, Wood did not observe any signs of structural distress that would warrant a structural capacity evaluation of these outlet culvert structures.

The visual inspection of the East Rambo FCF was limited due to culvert access restrictions and therefore, Wood cannot comment on the balance of the structural integrity of this structure. However, it is Wood's professional opinion that the existing outlet culvert structure would not experience increased levels of concrete damage or increased load effects under a major storm event and therefore, it is Wood's recommendation to obtain any condition assessments completed by MTO to determine if there is any structural distress noted that would warrant a structural capacity evaluation. If past condition surveys do not note any existing structural defects that would decrease the structural capacity, it is Wood's professional opinion that a structure capacity evaluation would not be required to assess the impact of a major storm event on the outlet culvert structure.

It should be noted that Wood has not carried out formal or intrusive structural capacity evaluations of the culverts and Wood is only commenting on the observed structural condition of the culverts and not their calculated structural capacity.

3.0 Geotechnical Assessment

A visual inspection, subsurface investigation, and numerical analysis were used to assess the stability of the existing berms at the West Hager, Freeman, and East Rambo Flood Control Facilities (FCFs). The following subsections provide a summary of the geotechnical assessment.

3.1 Visual Inspection

A visual slope inspection was conducted by a geotechnical engineer in June 2019. The berms and slopes within the pond limits were inspected for signs of instability. Site photos from June 2019 and March 2020 are included in Appendix B.

West Hager FCF

The berm is well vegetated with sparse trees/brush. No visible signs of surficial erosion (no rills/gullies, or under cutting at the base) or evidence of seepage.

Shallow slope failure/slough near the top of slope of the east bank of the Upper Hager Creek at 1767 Heather Hills Drive (Photos 2 and 3 of Appendix B). Exposed geotextile visible indicating this was previously stabilized slope. Silt fencing located on the creek bank and temporary barriers at the top indicate the area is known. This area was above the top of berm elevation, therefore is not part of the West Hager FCF, and outside the project limits. It is included for information.

Freeman FCF

The berm is well vegetated with sparse trees/brush. No visible signs of surficial erosion (no rills/gullies, or under cutting at the base) or evidence of seepage.

East Rambo FCF

The berm is well vegetated with sparse trees/brush. No visible signs of surficial erosion (no rills/gullies, or under cutting at the base) or evidence of seepage.

Localized undermining of the corrugated steel pipe on the outside of the pond was noted at the culvert that runs from the FCF to the rail ditch, as mentioned previously in the functional review of Section 2.2 (Photo 7 of Appendix B). Rip rap placement or other protection/replacement methods should be considered to ensure continued performance of the culvert and prevent continued erosion of the berm. Co-ordinates of the approximate location are 4800356 N, 596384 E.

3.2 Subsurface Investigation

A total of six (6) boreholes were advanced between February 10 to 11, 2020. A summary of the completed boreholes is provided in Table 3.1; location figures and borehole sheets are provided in Appendix B.

Table 3.1	Borehole Summary					
Location	BH	Co-ordinates (NAD83) +/- 3 m		Elevation[1] (m)	Borehole Details	
		Northing	Easting		Depth (m)	Monitoring Well
West Hager	1	4798767	594356	115.8	9.3	Yes
Freeman	2	4798729	595067	104.7	9.3	Yes
	3	4798976	595233	105.2	6.3	Yes
	4	4799128	595375	105.2	6.2	No
East Rambo	5	-	-	-	-	-
	6	4800335	596400	104.8	4.0	Yes
	7	4800425	596548	105.9	3.2	No

1. Extracted from LiDAR data (2018 CH Data – CGVD2013 Datum) based on GPS co-ordinates

Two (2) separate attempts (on February 11, 2020, and March 13, 2020) were made to complete an additional borehole (BH5) at the East Rambo FCF. The borehole was not completed due to identified utility conflicts. After review of the data from the completed boreholes, visual inspection, and LiDAR topography, the additional borehole is not anticipated to impact the berm stability findings and therefore the borehole will not be drilled.

The berms at West Hager and Freeman FCFs are constructed from silty clay / clayey silt fill (approximately 4 to 7 m in thickness), overlying a very dense silt till, overlying shale bedrock. The berm at East Rambo FCF consists of dense silt overlying very dense silt till, overlying shale bedrock.

All boreholes were open and dry upon completion of drilling through overburden, a secondary water level reading was measured on March 13th, 2020. Monitoring wells were installed at four (4) locations and were constructed with 5 cm diameter schedule 40 PVC pipe with 3.1 m length #10 mil slotted screen, No. 2 sand, and stickup monument protective casings. Table 3.2 provides a summary of the groundwater observations.

Table 3.2	Monitoring Wells Readings			
Location	BH	Water Level Below Ground Surface / Elevation (mbgs) / (m)		
		February 10, 2020*	February 11, 2020*	March 13, 2020
West Hager	BH/MW-1	Dry		8.1 / 107.7
Freeman	BH/MW-2		Dry	7.0 / 97.7
	BH/MW-3		Dry	5.4 / 99.8
East Rambo	BH/MW-6		Dry	3.0 / 101.8

*upon completion

It should be noted that the groundwater conditions will vary subject to weather and seasonal fluctuations. This area is part of a storm water management system and the toe of the berm often becomes submerged during precipitation events.

3.3 Slope Stability

A typical berm section has been modelled for each FCF. The geometry has been extracted from the LiDAR data provided by the City (2018 CH Data). The soil properties have been estimated based on the geotechnical subsurface investigation (as per Section 3.2). The groundwater conditions have been modelled using the observed water level in the wells along with a short-term elevated water level within the pond.

Geostudio Slope/W (2016) software with the Morgenstern-Price limit equilibrium method has been used to perform the analysis. The existing condition has been checked for both short-term (total stress) and long-term (effective stress) conditions. The slope stability models are provided in Appendix B. Soil properties used are provided on the analysis figures.

A surcharge of 15 kPa has been used for maintenance equipment loading during the short-term condition.

The Ontario Ministry of Natural Resources (MNR) Technical Guide for River & Stream: Erosion Hazard Limit (2002) provides a minimum recommended design Factor of Safety for different land uses and associated risk to property and life. Based on the current land use for the East Rambo FCF (berm supporting high voltage hydro towers), *Category D 'Infrastructure and Public Use'* a design minimum factor of safety of 1.40 to 1.50 is recommended. Both West Hager and Freeman FCF berms do not support any infrastructure but are flood control facilities, therefore, *Category C 'Active'* with a design minimum factor of safety of 1.30 to 1.50 is recommended.

The Lakes and Rivers Improvement Act by the MNR (1990) provides further guidance for dam structures. Additional temporary loading conditions and commentary are provided in the Technical Bulletin for Geotechnical Design and Factors of Safety, 2011. The pseudo-static and rapid drawdown conditions from the technical bulletin have been considered in this assessment.

For the pseudo-static analysis, a conservative horizontal seismic coefficient, k_h=0.1 has been used. The Peak Ground Acceleration (PGA) from the National Building Code of Canada (2015) in the general pond area is between 0.1g and 0.2g based on the online seismic hazard tool from Natural Resources Canada. Based on a PGA of 0.2g, and a horizontal seismic coefficient equal to half the PGA, a value of 0.1 has been determined.

For the rapid drawdown analysis, the conservative approach of an instantaneous drop in the water level from the maximum normal operating level to normal operating level has been performed. The porewater conditions within the berm are based on the maximum operating level and do not benefit from a lowering which would be expected to occur during the time it takes for the pond water level to go from maximum level to normal level.

A summary of the slope results is listed in the Table 3.3. Supporting figures are provided in Appendix B.

The existing slope has been found to meet or exceed the Ontario Ministry of Natural Resources (MNR) *Technical Guide River & Stream Systems: Erosion Hazard Limit* and the *Lakes and Rivers Improvement Act - Technical Bulletin for Geotechnical Design and Factors of Safety* minimum recommended design factor of safety. Based on this finding and the visual inspections, the existing berms are deemed stable with an adequate factor of safety during both short term and long-term conditions.

Berms and embankments outside the flood control facility site limits such as local highway and road embankments have not been considered and are beyond the current scope of work.

The West Hager Creek banks have also not been assessed. It should be noted that the visual inspection noted a shallow slope failure/slough near the top of slope of the east bank of the Upper Hager Creek at 1767 Heather Hills Drive. Geotextile was exposed indicating this was a previously (recently) stabilized slope. This area was above the top of berm elevation, therefore is not considered an active part of the West Hager flood control storage area. Further, it is noted that the City of Burlington is aware of the issue and has undertaken measures to address the issue.

Table 3.3	Slope Stability				
Location	**Slope Inclination**	**Condition**	**Calculated Factor of Safety**	**Required Factor of Safety**	**Figure**
West Hager	3H: 1V	Short-term: pond empty	2.51	1.4[1] / 1.3[2]	1
		Short-term: pond full	3.88	1.4[1] / 1.5[2]	2
		Long-term: pond empty	1.87	1.4[1] / 1.5[2]	3
		Short-term: pseudo-static	1.86	1.0[2]	4
		Short-term: rapid drawdown	1.34	1.2[2]	5
Freeman	2H: 1V inside 2.5H: 1V outside	Short-term: pond empty	2.11	1.3[1] / 1.3[2]	6
		Short-term: pond full	2.93	1.3[1] / 1.5[2]	7
		Long-term: pond empty	1.49	1.3[1] / 1.5[2]	8
		Short-term: pseudo-static	1.63	1.0[2]	9
		Short-term: rapid drawdown	1.88	1.2[2]	10
East Rambo	3H: 1V	Short-term: pond empty	1.68	1.3[1] / 1.3[2]	11
		Short-term: pond full	1.56	1.3[1] / 1.5[2]	12
		Long-term: pond empty	1.72	1.3[1] / 1.5[2]	13
		Short-term: pseudo-static	1.25	1.0[2]	14
		Short-term: rapid drawdown	1.20	1.2[2]	15

1. Based on land use from Technical Guide for River & Stream: Erosion Hazard Limit (2002)
2. Based on the Lakes and Rivers Improvement Act - Technical Bulletin for Geotechnical Design and Factors of Safety (2011)

4.0 Flood Control Capacity and Performance Assessment

4.1 Topographic Data

As part of the original Flood Hazard and Scoped Stormwater Management Assessment for the Burlington GO Mobility Hubs and Downtown area, Wood used the best available topographic data at the outset of the study, namely the Region of Halton's 2015 Digital Elevation Model (DEM).

During the latter stages of the completion of the flood hazard assessment, it was noted that Conservation Halton (CH) had obtained a high-resolution LiDAR based DEM for the study area (2018 LiDAR data from Airborne Imaging). These data were subsequently provided to Wood for use in the current flood control facility (FCF) assessment, via the City of Burlington through a formal data sharing agreement. The intent of the current assessment is to re-confirm any potential differences in estimated storage volume for the three (3) FCFs within the study limits, and any associated potential impacts to peak flow attenuation within downstream receivers, and thus, potential floodplain extents.

To further support this effort, Wood also undertook a scoped topographic survey verification using GPS-based survey equipment, as outlined further as part of the current discussion.

A clear difference between the two DEMs (beyond differences in horizontal and vertical resolution/accuracy) is the vertical datum employed. The original Region of Halton DEM (2015) is understood to be in the typically employed (in Southern Ontario) Canadian Geodetic Vertical Datum of 1928, incorporating the 1978 Southern Ontario adjustment (typically referred to as the 1928/1978 datum). This datum is the one currently applied by the City of Burlington, including for record drawings. Notwithstanding, more recently, an updated vertical datum, known as the Canadian Geodetic Vertical Datum 2013 (CGVD 2013) has been increasingly used, including recent LiDAR collection efforts by MNRF and OMAFRA. The updated 2018 LiDAR data from CH are set using this updated CGVD2013 datum. As such, the two datasets are not directly comparable unless converted to a consistent vertical datum.

As an initial verification, Wood surveyed a local Provincial benchmark through the COSINE system, located as the Orpha Street pedestrian bridge (directly north of Drury Lane and Fairview Street). Based on the COSINE data for this location, the elevation of the benchmark is 99.444 m (CGVD2013) or 99.867 m (1928/78). Thus, the data in the CGVD2013 datum are some 0.423 m lower than in the 1928/78 datum. Wood's surveyed elevation (CGVD2013) was 99.387 m, or 0.057 m lower than the stated elevation. This likely reflects the accuracy of the survey equipment, which is typically 0.05 m +\-.

Topographic survey verifications were completed in a number of critical locations, including inlets, outlets and spill elevations of both the East Rambo and Freeman FCFs (given their direct hydrologic impact on the study area), as well as a scoped verification of the Hager-Rambo Diversion Channel along Fairview Street. The topographic survey was completed in December 2019 and extended due to weather conditions to February 2020 . Figures presenting the collected survey data are included in Appendix C. A comparison of key elevations is presented in Table 4.1.

Table 4.1	Comparison of Key Facility Elevations				
Location	Feature	Previously Estimated		Updated Elevation (CGVD 2013)	
		1928/1978	Adjusted (CGVD 2013)[1]	2018 LiDAR (As Received)	Survey
East Rambo	Outlet Invert	103.30	102.87	102.78	102.76
	Railway Spill	105.50	105.07	104.75 (Ditch) 104.90 (Rail at Face) 104.97 (Rail U/S)[2]	105.03[2]
	NSR Spill	106.40	105.97	106.06	106.12
Freeman	Outlet Invert	98.40	97.97	97.54	97.44
	Outlet Spillway	104.90	104.47	104.29 (Fence) 104.58 (Berm)	104.19 (Fence) 104.51 (Berm)
	East Berm Spill	105.20	104.77	104.95	104.90

1. Based on COSINE adjustment of -0.426 m.
2. Surveyed at the centre of the rails approximately 20 m upstream of culvert face

With respect to the East Rambo FCF, the surveyed data are generally in good agreement with the previously applied values, with difference ranging from -0.11 m to +0.15 m. The largest difference is evident when comparing the results from the 2018 DEM at the railway spill location, which indicates that that spill would start at a lower elevation than previously estimated.

With respect to the Freeman FCF, the previously estimated elevation of the outlet is notably different from that obtained from the 2018 DEM or survey (between 0.43 m and 0.53 m lower). Other values are generally more comparable, such as the lowest spill elevation along the berm near the outlet (differences of 0.04 to 0.11 m). Of note is that both the completed survey and 2018 DEM, suggest the lowest point is actually along the fence line between the Freeman FCF and the QEW/Hwy 403, and that this elevation is somewhat lower than the previously estimated value. Contrarily, the spill elevation at the east end of the Freeman FCF is somewhat higher than previously estimated, which suggests primary spill would occur at the downstream end for a longer period of time, as was the original design intent. Notwithstanding, a further review of the potential for spill via the upstream ponding area at the east end of the Freeman FCF via the QEW/Hwy 403 Brant Street off-ramp, requires further review. This area could not be surveyed due to safety concerns related to highway vehicular operations.

A more detailed assessment of the respective FCF rating curves is presented in Section 4.2.

4.2 Flood Control Facilities

4.2.1 East Rambo Pond

4.2.1.1 Base Rating Curve Development

Of particular note for the current area of interest is the assumption regarding the performance of the East Rambo Pond (refer to Drawing 2). Based on the available documentation, this facility was designed to a 100-year level of flood control (using the 1997 3-hour Chicago storm distribution), with minimal freeboard (i.e. < 0.30 m). Above the design level, the facility would be expected to spill without appreciable attenuation. Given the anticipated increase in flows associated with the application of current IDF data (and a longer duration design storm event), the facility would be expected to spill for the (current) 100-year storm event, as well as for the Regional Storm (Hurricane Hazel) event.

The Flood Control facility rating curve included in the 1997 modelling (ref. "Hager-Rambo System Hydrology Update", Philips Planning and Engineering, 1997) is understood to be a preliminary design curve not based on as-constructed conditions; the facility underwent detailed design and construction by the MTO sometime between 1997 and 2004 (given that the facility is evident in historical aerial photography for that date). There are no available records within the City of Burlington's files which provide a detailed design summary or associated detailed design rating curve. Attempts were made by Wood to obtain design information from the MTO; however, these attempts were ultimately unsuccessful.

Low flow from the East Rambo Pond is drained by a 3 m wide by 1.5 m high concrete box at the western limits of the facility (field verified October 13, 2017). This conduit is ultimately directed to a 2.4 m x 1.8 m storm sewer beneath the QEW, which outlets to the East Rambo Creek at Queensway Drive at Brenda Crescent. The 1997 rating curve and modelling assumed that spill/overflow from the East Rambo Pond would continue to be directed towards the East Rambo Creek system. As alluded to in comments from Conservation Halton (September 12, 2017; refer to "Flood Hazard and Scoped Stormwater Management Assessment" January, 2020), the CNR underpass may serve as an unintentional overflow from the FCF. Based on Wood's further review of available topographic data (originally based on the Region of Halton's 2015 DEM, (the best available topographic data at the outset of the preceding study), it appears that spill above the maximum operating level would in fact be directed to the CNR underpass beneath the North Service Road and the QEW, and then ultimately drain westerly into the West Rambo Creek system. The railway elevation (from the 2015 Region of Halton DEM) of 105.5 m +\- is the lowest point of potential spill. The 15 m +\- wide underpass opening appears to have a continuous 0.9% grade to the south of the QEW. Secondary spill from the East Rambo Pond across the North Service Road would not occur until a higher elevation is reached, 106.4 m +\- (or some 0.9 m +\- higher), based on the 2015 DEM.

Originally, as part of the flood hazard assessment, an updated rating curve for the East Rambo Pond was developed. The 2015 Region of Halton DEM was used to develop 0.25 m elevation contours, and thus establish the stage-surface area relationship for the facility, and in turn the stage-storage relationship. This topographic information was considered the best available during the preceding study (and also reasonable given the scale of the facility). Updated topographic data are considered in subsequent sections.

The corresponding stage-discharge function was determined by summing the three potential discharge outlets for the facility:

- Low flow discharge through the 3 m W x 1.5 m H box culvert was estimated using an approximation of MTO Design Chart 5.39 (inlet control of a box culvert)
- Primary spill via the CNR to the west was estimated using Manning's equation for flow through the culvert structure
- Secondary spill via the NSR was estimated using Manning's equation to approximate a weir type overflow

Figure 4.1 presents a comparison of the facility rating curve from the 1997 report (ref. "Hager-Rambo System Hydrology Update", Philips Planning and Engineering, 1997), as well as the updated rating curve based on 2015 Region of Halton DEM, as applied in "Flood Hazard and Scoped Stormwater Management Assessment" (Wood, January, 2020).

As evident from Figure 4.1, the previously proposed rating curve indicates a lower rate of discharge at lower storage volumes, which would tend to result in a more rapid consumption of available storage volume. Both curves have a similar "break point" between low and high (spill flow), at approximately 11 to 12 ha-m (110,000 to 120,00 m^3). The spill portion of the proposed rating curve is further extended, which likely reflects the use of actual data (as compared to the approximations which were likely necessary for the preliminary 1997 curve).

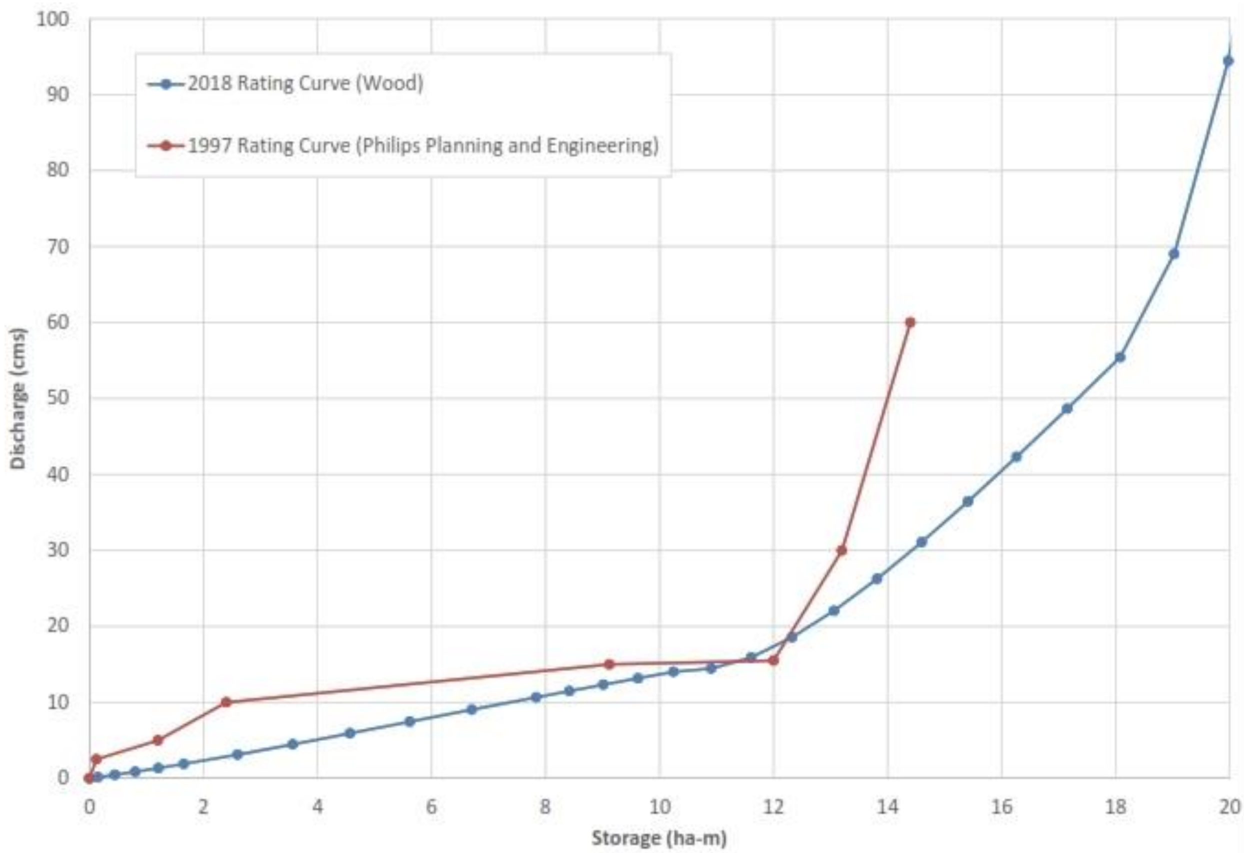

Figure 4.1: Previous Rating Curve Comparison for East Rambo Pond

The updated (2018) rating curve was subsequently incorporated into the updated hydrologic modelling in SWMHYMO. A DIVERT HYD command was used to separate the combined discharge into its constituent components: culvert flow (to East Rambo Creek), CNR spill flow (to West Rambo Creek) and North Service Road spill flow (assumed to be ultimately directed to East Rambo Creek via the culvert crossing of the QEW to the south).

It should be noted that a scenario considering debris blockage of the outlet has not been considered as part of the current assessment.

4.2.1.2 Updated Rating Curve Development

The updated rating curve developed as part of "Flood Hazard and Scoped Stormwater Management Assessment" (Wood, January 2020) has been revisited as part of the current study on the basis of the updated topographic data made available by CH and the City. This includes both the 2018 DEM (as provided by Conservation Halton) as well as a scoped topographic survey completed by Wood, as outlined in Section 4.1. Both of the preceding have employed the CGVD2013 datum, which differs from the 1978 datum employed previously.

The same methodology described in Section 4.2.1.1 has been applied for the development of the updated rating curve. The 1 m DEM has been used to again generate 0.25 m contours, which have been used to establish an updated stage-surface area and stage-storage relationship. It should be noted that at higher elevations, the East Rambo Pond will spill over the CNR tracks to the north, and ultimately towards the private properties to the north of the CNR tracks (i.e. fronting on Industrial Street), as well as to the lands to the west of East Rambo Creek. For the purposes of the updated stage-surface area and stage-storage relationship, only the primary area of the East Rambo FCF and areas along the CNR corridor have been included (given that this area will ultimately spill towards West Rambo Creek via the CNR underpass of the QEW). Additional surface areas beyond these limits have not been credited, although they would, in reality be inundated at such flood elevations. A comparison of the resulting stage-storage relationships (converted to a consistent 1978 vertical elevation datum) is presented in Figure 4.2.

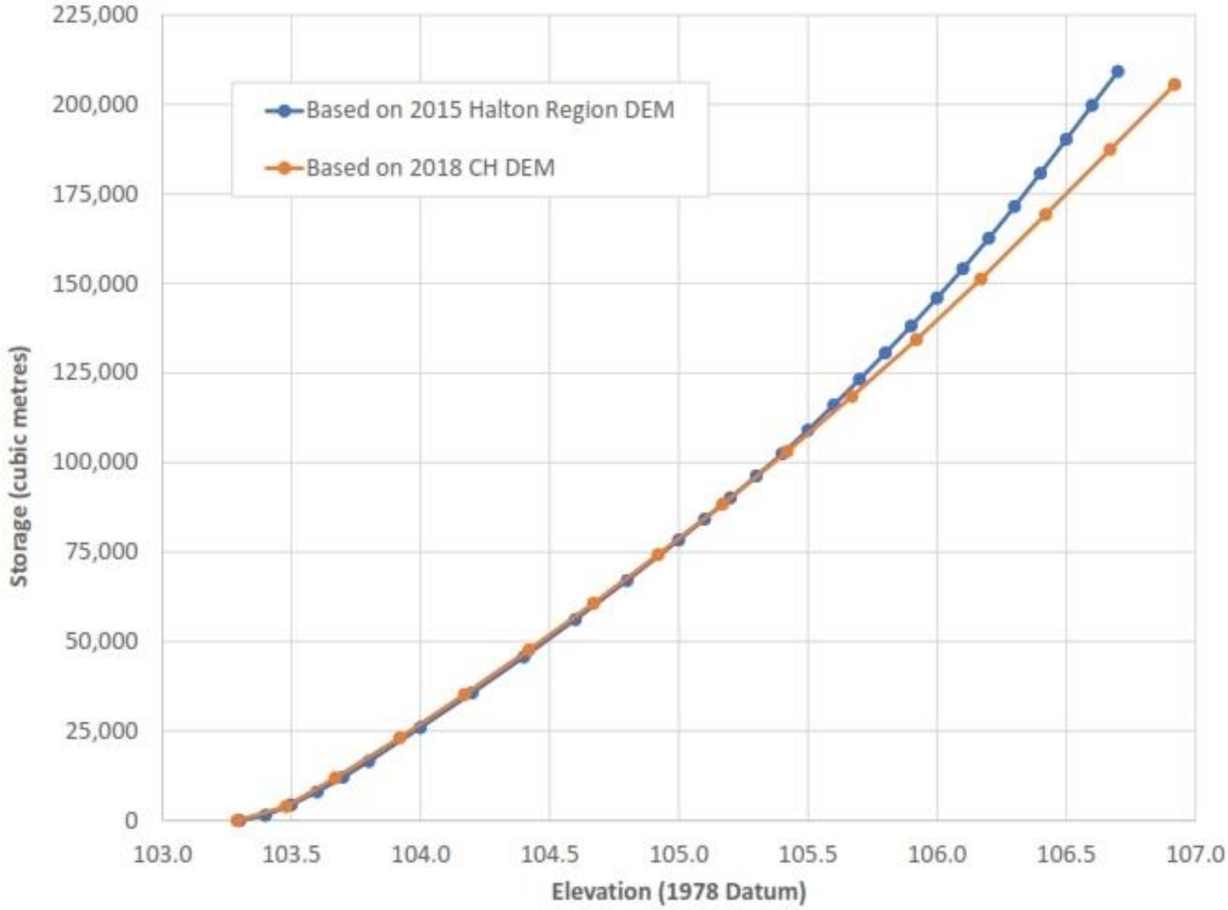

Figure 4.2: Stage-Storage Rating Curve comparison for East Rambo FCF

As evident from Figure 4.2, the two sources of topographic data indicate near complete agreement up to an elevation of approximately 105.5 m. Above this elevation, the curves begin to indicate greater variation, with the 2015 Halton Region DEM indicating a greater amount of potentially available storage. Upon review, it is considered that this difference is attributable more to the assumptions around credited surface area than actual differences in the topographic data sources. As noted previously, the current update has not included crediting of ponding/surface area on private property or beyond the limits of the East Rambo FCF and CNR track corridor. The previously assessed rating curve included these areas, given that they would actually be inundated in reality. Notwithstanding, removal of these additional areas in the current update, while more conservative, results in the reduction in available storage evident in Figure 4.2.

The preceding updated stage-storage curve has been combined with an updated stage-discharge relationship using the same approach as described with respect to the original rating curve (Section 4.2.1.1). An updated base FCF elevation of 102.87m (CGVD 2013) has been applied based on the 2018 CH DEM. The surveyed invert elevation in this location is further within the enclosure, and thus does not accurately represent the edge of the structure which sets the permanent pool elevation. The proposed elevation of 102.87 m more accurately represents the edge of the inlet control structure at the interface with the FCF, which would be the actual spill/control elevation.

Based on the updated 2018 CH DEM, spill via the CNR underpass structure of the QEW would be expected to occur at a slightly lower elevation than previously estimated. The 2018 DEM indicates spill occurring at approximately 104.75 m (CGVD2013). This converts to an elevation of approximately 105.17 m (1978 datum) which is some 0.33 m lower than the previously estimated spill elevation (105.5 m in the 1978 datum). The representative cross-section for spill through the CNR underpass has also been slightly modified based on the updated 2018 CH DEM, including representations of rail side ditches, and an updated width (14 m rather than the previously applied 15 m) and slope (0.7% rather than the previously applied 0.9%). Thus, although CNR spill would occur at a lower elevation the actual drainage capacity would be somewhat less.

With respect to secondary spill via the North Service Road, a cross-section along the centerline of the road was extracted from the 2018 CH DEM. A representative trapezoidal form was again estimated, with an average spill elevation of 106.09 m (CGVD2013), based on the average of the DEM value of 106.06 m and surveyed value of 106.12 m. Contrarily to the CNR spill elevation, this elevation is somewhat higher than previously estimated, 106.52 m (1978 datum), which is greater than the elevation of 106.4 m previously estimated. A 44 m wide base spill section has been estimated from the updated topography, notably wider than that in the previous rating curve (25 m).

The resulting combined updated storage-discharge curve is presented in Figure 4.3 along with the previously developed curve described in Section 4.2.1.1.

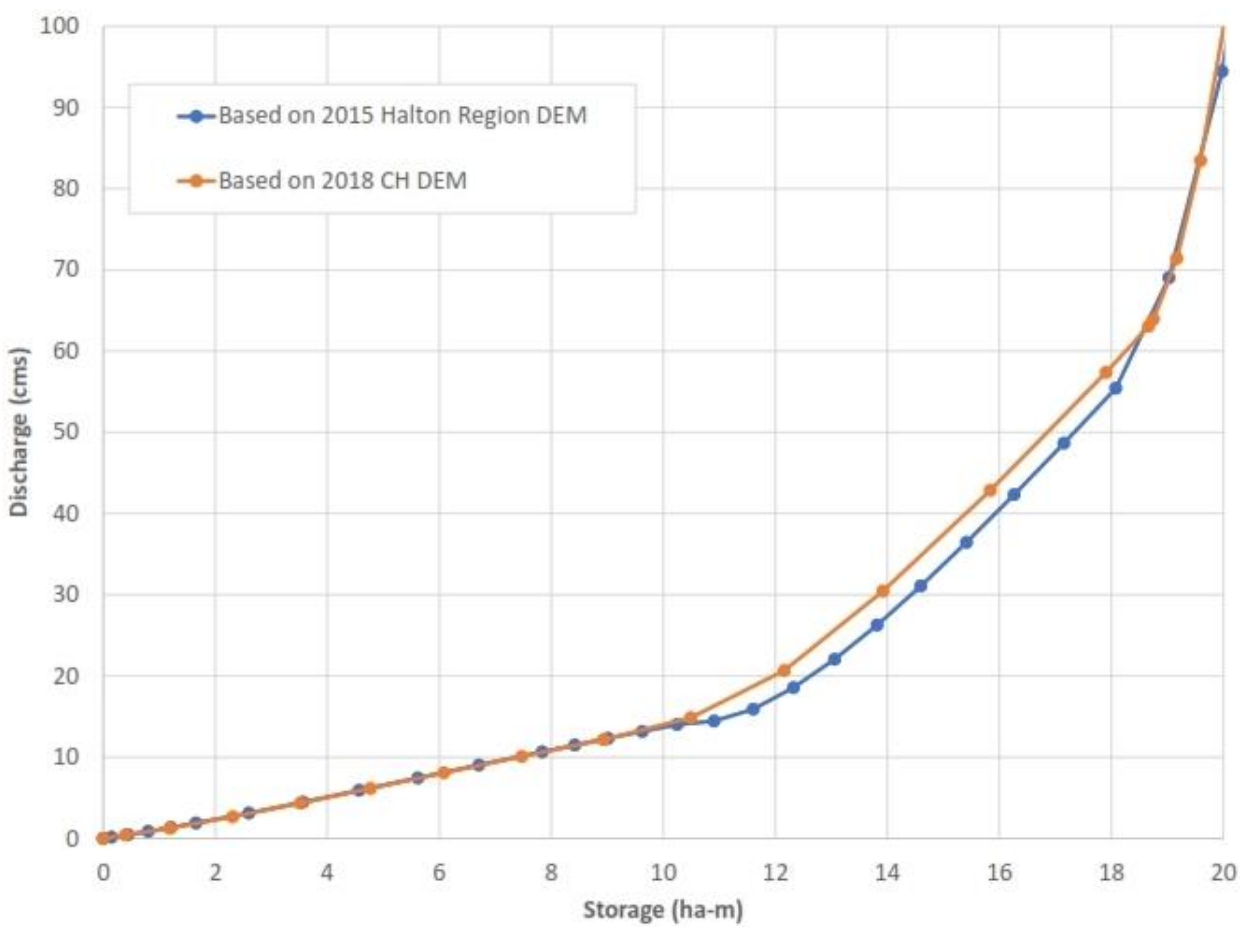

Figure 4.3: Storage-Discharge Rating Curve comparison for East Rambo FCF

Overall, the two curves match closely up to approximately 10 ha-m (100,000 m^3), similar to Figure 4.2. Above this point, the updated rating curve indicates a slightly greater discharge for the same storage, which reflects the combination of lower CNR spill threshold and removal of crediting of surface storage area beyond the CNR tracks. At the upper end of the rating curve, the curves again indicate close agreement. Overall, the two curves are very similar, however the impact of the updated curve has been assessed using hydrologic modelling, as presented in Section 4.3.

4.2.2 Freeman Pond

4.2.2.1 Base Rating Curve Development

The Freeman Pond is a large flood control facility located on the south side of the QEW/Hwy 403 interchange (refer to Drawing 3). The facility attenuates flows to the East Hager Creek system. While East Hager Creek is outside of the limits of the Burlington Mobility Hub, previous floodplain mapping prepared by CH (ref. March 18, 2014 memorandum Lee/Harris-Brouwers) indicated that the Regional Storm Floodplain could potentially impact the subject Mobility Hub. As such, further assessment by Wood was required.

The Freeman Pond was designed by Philips Planning and Engineering; construction was completed in October 1995 (as per the Hager-Rambo Flood Control Works Operations & Maintenance Manual, Philips Planning and Engineering, December 17, 1998; a copy has been included in Appendix A for reference purposes). A facility rating curve was included with the available modelling (the originally approved hydrologic modelling for the Hager-Rambo system is the 1997 OTTHYMO model, as noted previously). The Regional Storm modelling includes an overflow ordinate, which was noted previously by Wood to cause some model stability issues (given the minimal corresponding increase in storage and the difficulty of the model in interpolating intermediate values). The available documentation for the Freeman Pond does not indicate the corresponding expected stage/depth and surface area values which relate to the available storage and discharge values. As such, it was considered inappropriate to estimate or assume a modified overflow function for the rating curve. A new facility rating curve was therefore developed based on currently available topography data (then the 2015 Region of Halton DEM) and associated field confirmation of features.

Low flow from the flood control facility is via a 1.75 m x 1.75 m concrete box culvert. These dimensions were field verified, and match with record drawings. Notwithstanding, a low flow channel is also present below the primary box (approximately 0.25 m deep, 0.5 m wide at the base and 0.5 m wide at the top). Based on this additional conveyance area, an equivalent dimension of 1.85 m H by 1.75 m W would result. The invert of the outlet control structure was estimated based on topographic mapping data (2015 Region of Halton DEM) with an elevation of 98.4 m (somewhat higher than the elevation of 97.9 m indicated on record drawings; the invert was field surveyed as part of the current scope of work as discussed further in Section 4.2.2.2).

There is conflicting information on the designed top of berm amongst available record drawings. One drawing indicates a spillway elevation of 105.15 m, while other drawings or portion of the O&M report indicate 105.4 m and 105.5 m (with a noted length of 107 m). Based on the previously noted DEM data, the low point along the berm is approximately 104.9 m. The elevation rises from this location, up to an elevation of approximately 105.6 m. The base spillway width varies, but is approximately 102 m +\- which is generally consistent with the value reported in the O&M manual.

It should be noted that based on the previous topographic data (2015 DEM) there are two (2) locations where spill was indicated as having the potential to occur at a lower elevation than noted in the O&M manual and other documentation. These locations are presented in Figure 4.4, and include:

- Along the north-east side of the primary Freeman Pond Berm (along Brant Street off-ramp, 125 m +\- west of Brant Street)
- From the smaller upstream ponding area on the north side of the Brant Street off-ramp

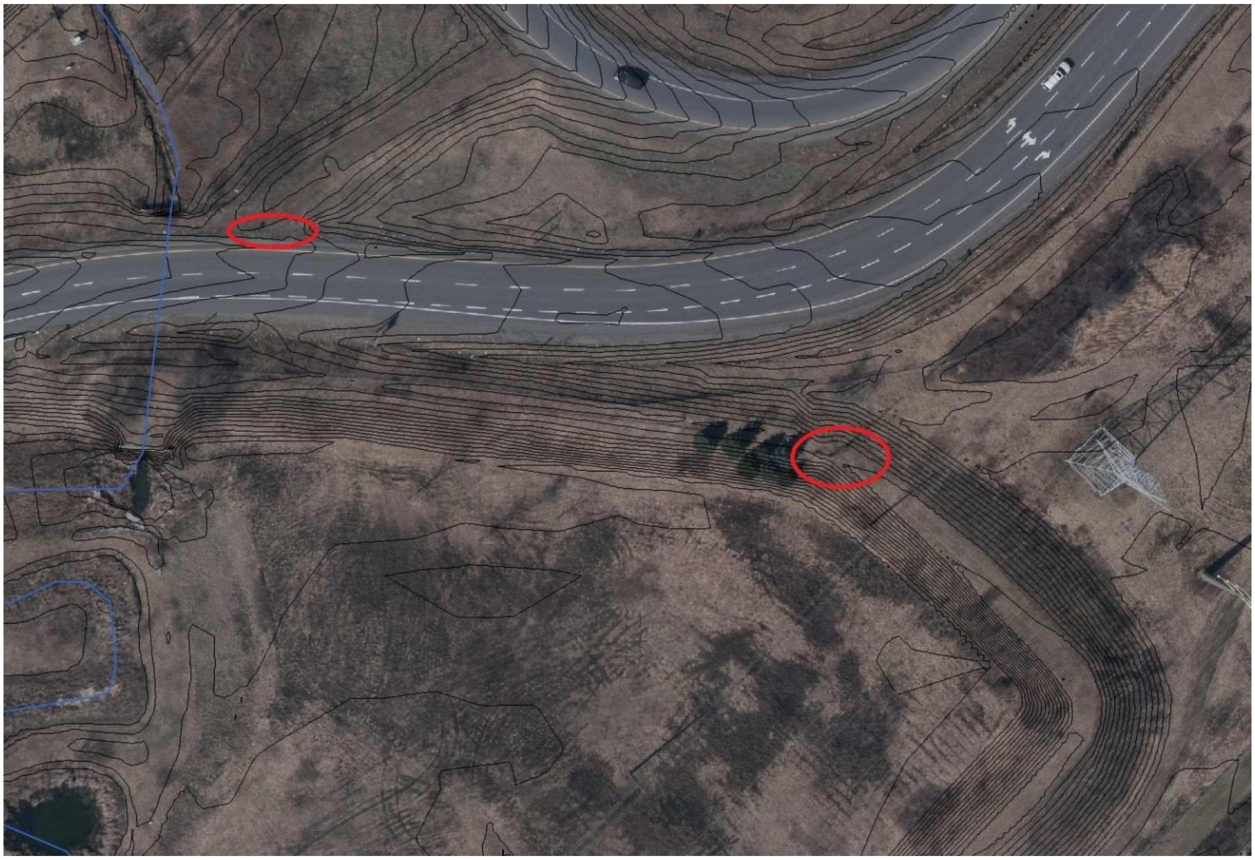

Figure 4.4: Potential Spill Locations from the Freeman Pond

Potential spill in these locations was indicated as potentially occurring at an elevation of 105.2 m +\- based on the 2015 Region of Halton DEM, which while higher than the estimated lowest spillway elevation of 104.9 m +\-, is below the typical top of berm elevation and previously reported berm heights. Other locations on the south side of the berm indicate low elevations of approximately 105.4 m. These potential spill issues have been revisited as part of the updated assessment discussed herein, as detailed further in Section 4.2.2.2. As part of the previous assessment, it was assumed that all spill from the Freeman Pond would be via the primary spillway at the west limits of the pond, draining to East Hager Creek.

An updated rating curve for the Freeman Pond was developed for the previous study based on the preceding. The 2015 Region of Halton DEM was used to develop 0.25 m elevation contours, and thus establish the stage-surface area relationship for the facility, and in turn the stage-storage relationship. Surface areas for the facility reflect the primary Freeman Pond, as well as the two adjacent ponding areas upstream of the main pond and downstream of the QEW. As noted for the East Rambo Pond, this topographic information was considered the best available for the original study (and also reasonable given the scale of the facility). Updated topographic data are considered further in a subsequent section.

The corresponding stage-discharge function was determined by summing the two (2) potential discharge outlets for the facility:

- Low flow discharge through the equivalent 1.75 m W x 1.85 m H box culvert was estimated using an approximation of MTO Design Chart 5.39 (inlet control of a box culvert)

- Primary spill via the overflow spillway was estimated using Manning's Equation (given the irregular geometry) in order to estimate a weir type overflow

Figure 4.5 presents a comparison of the facility rating curve from previous hydrologic modelling (SWMHYMO), as well as the currently proposed rating curve.

As evident from Figure 4.5, the two rating curves are generally consistent for the majority of the operating range. The previously proposed (2018) rating curve indicates a slightly lower rate of discharge at lower storage volumes, which would tend to result in a slightly more rapid consumption of available storage volume. Both curves have a similar "break point" between low and high (spill flow), at approximately 31 to 32 ha-m (310,000 to 320,000 m^3). The spill portion of the proposed rating curve is further extended, which reflects the use of actual data (as compared to the approximation in the previous modelling which did not appear to account for the actual increase in storage volume with increasing depth).

It should again be noted that a scenario considering debris blockage of the outlet has not been considered as part of the current assessment.

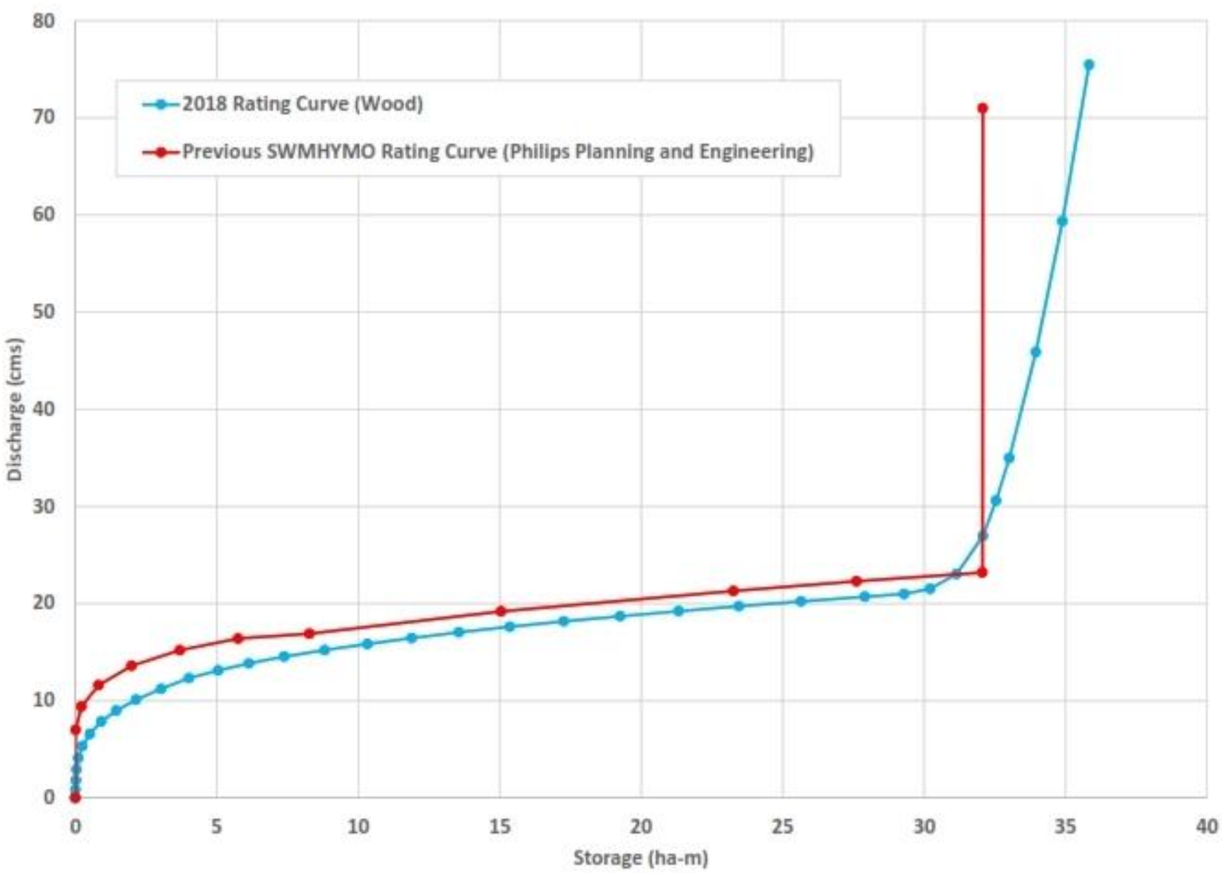

Figure 4.5: Previous Rating Curve Comparison for Freeman Pond

4.2.2.2 Updated Rating Curve Development

The updated rating curve developed as part of "Flood Hazard and Scoped Stormwater Management Assessment" (Wood, January 2020) has been revisited as part of the current study on the basis of the updated topographic data. This includes both the 2018 DEM (as provided by Conservation Halton) as well as a scoped topographic survey completed by Wood, as outlined in Section 4.1. Both of the preceding have employed the CGVD2013 datum, which differs from the 1978 datum employed previously.

The same methodology described in Section 4.2.2.1 has been applied for the development of the updated rating curve. The 1 m DEM has been used to again generate 0.25 m contours, which have been used to establish an updated stage-surface area and stage-storage relationship. As before, storage volumes have been summed based on the primary pond area, secondary pond area (to the north, directly adjacent to QEW), and the smaller tertiary storage area (refer to Drawing 3 for locations).

The invert of the Freeman Pond for the current assessment has been based on the survey completed by Wood, or 97.44 m (CGVD2013). This is notably lower than the previously estimated value from the 2015 Halton Region DEM (97.97 m in CGVD2013), however reasonably close to the original design value of 97.90 m (1978 datum), which translates to an elevation of 97.48 m (CGVD2013).

A comparison of the resulting stage-storage relationships (converted to a consistent 1978 vertical elevation datum) is presented in Figure 4.6.

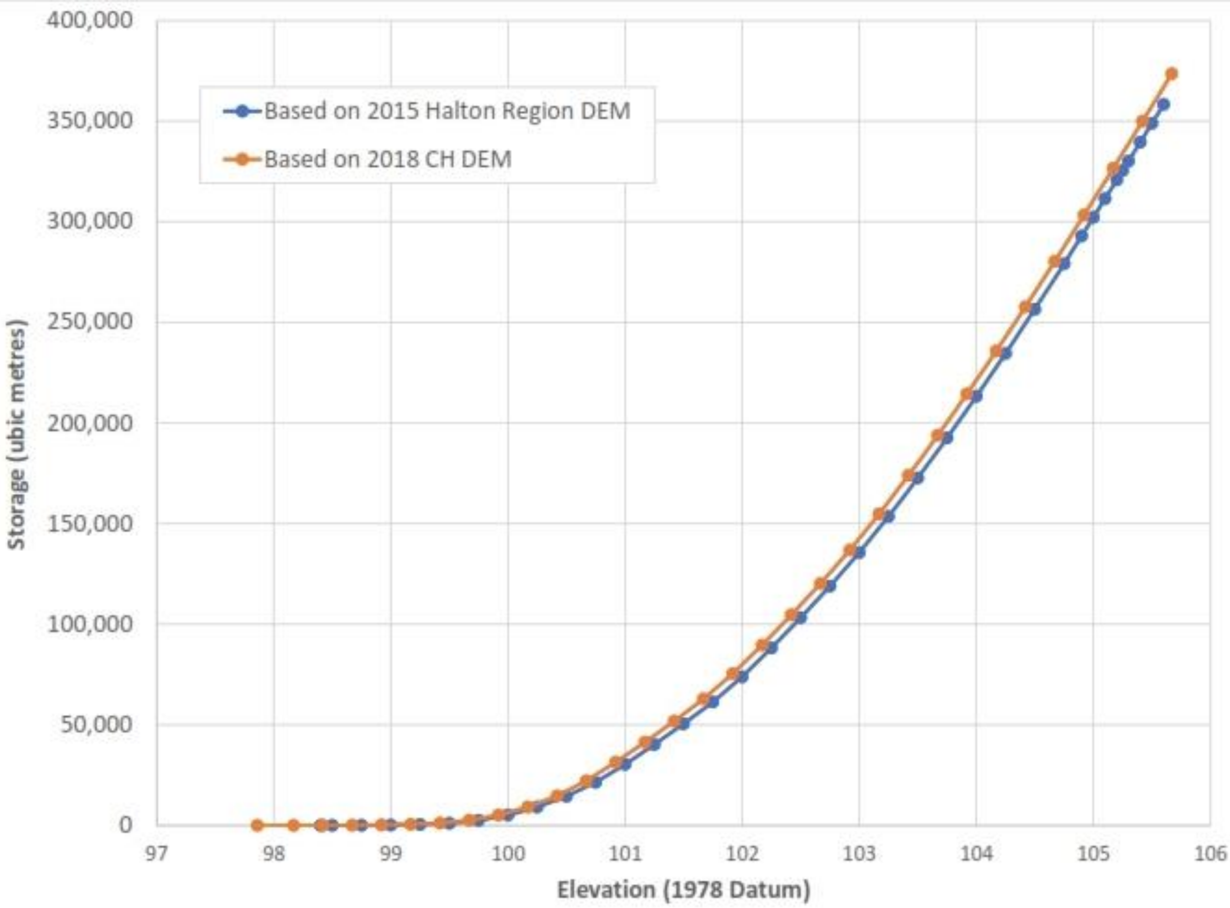

Figure 4.6: Stage-Storage Rating Curve Comparison for Freeman Pond

As evident from Figure 4.6, the two sources of topographic data indicate very close agreement. Some of the difference is likely attributable to the difference in assumed facility invert elevation, although minimal storage would result at such low elevations. Overall, the updated 2018 CH DEM generates consistently higher storage volumes for the entire length of the curve.

The preceding updated stage-storage curve has been combined with an updated stage-discharge relationship using the same approach as described with respect to the original rating curve (Section 4.2.2.1). As noted, an updated box culvert invert elevation of 97.44 m (CGVD 2013) has been applied based on the completed topographic survey.

Based on the completed topographic survey, a low spillway elevation of 104.19 m was measured (along the fence line adjacent to Highway 403/QEW). The 2018 CH DEM however indicates a lowest elevation of 104.29 m. The average elevation of 104.25 m has been applied for estimation of the spillway. A trapezoidal channel approximation of the spillway has been developed, with an initial 6 m base width at 104.25 m, and a much wider 120 m section at 104.7 m. Full overflow of the approximately 1 km top of berm would occur at an elevation of 105.0 m (CGVD2013).

Given the potential additional spill locations identified in Section 4.2.2.1 (along the Highway 403 off-ramp to Brant Street, and along the north-east side of the berm in the same location – refer to Figure 4.4), an additional assessment has been completed for the current study. As noted, topographic survey data could not be safely collected for the Highway 403 off-ramp, however the 2018 CH DEM has been used to review the spill potential in this location. Based on a section at the identified low point (refer to Figure 4.7), spill in this location would occur at an elevation of approximately 104.77 m (CGVD2013). Although this is well above the base spillway elevation of 104.25 m, the potential for spill at this location would depend on simulated FCF operating levels (i.e. whether or not the 100-Year or Regional Storm flood levels would actually be expected to reach this elevation). This is reviewed further in Section 4.3. The updated rating curve has not considered any loss of flow or spill from this location.

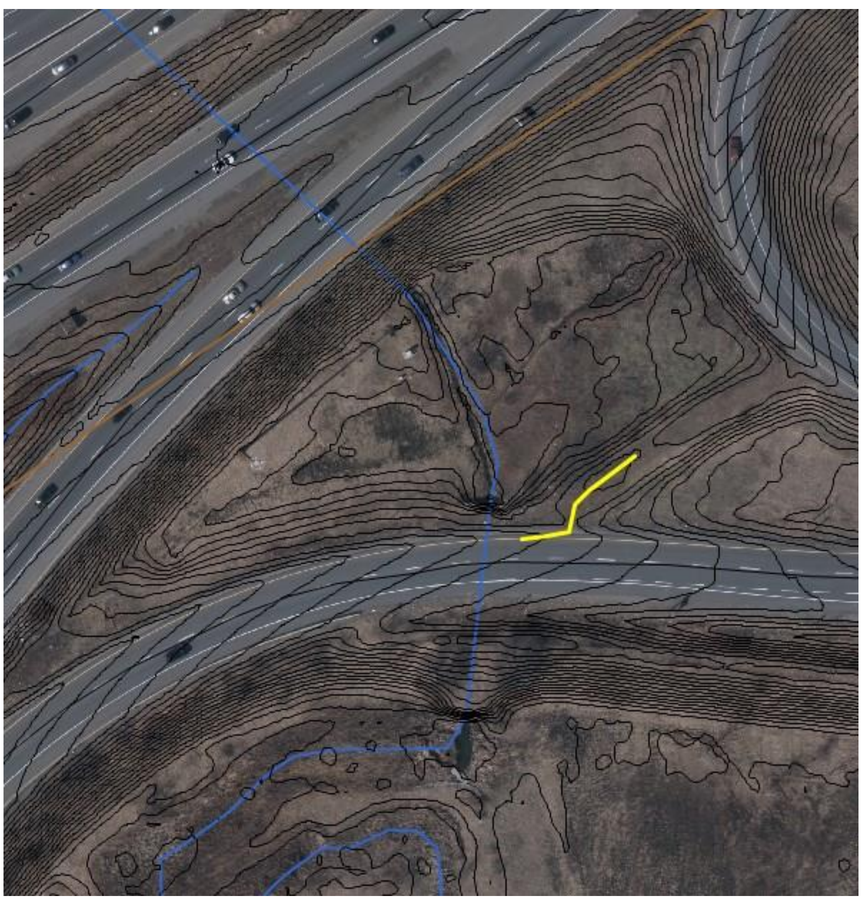

Figure 4.7: Cross-Section through potential Highway 403 Ramp Spill Point

Topographic survey along the north-east berm indicates a lowest elevation of 104.91 m (CGVD2013); the 2018 CH DEM indicates a lowest elevation of 104.94 m. Given that this elevation is reasonably close to the overall average elevation of 105.00 m for the balance of the top of berm (1 km +\- in length), no additional consideration of spill from this location has been included in the updated rating curve.

The resulting combined updated storage-discharge curve (based on outlet culvert and primary overflow spillway) is presented in Figure 4.8 along with the previously developed curve described in Section 4.2.2.1.

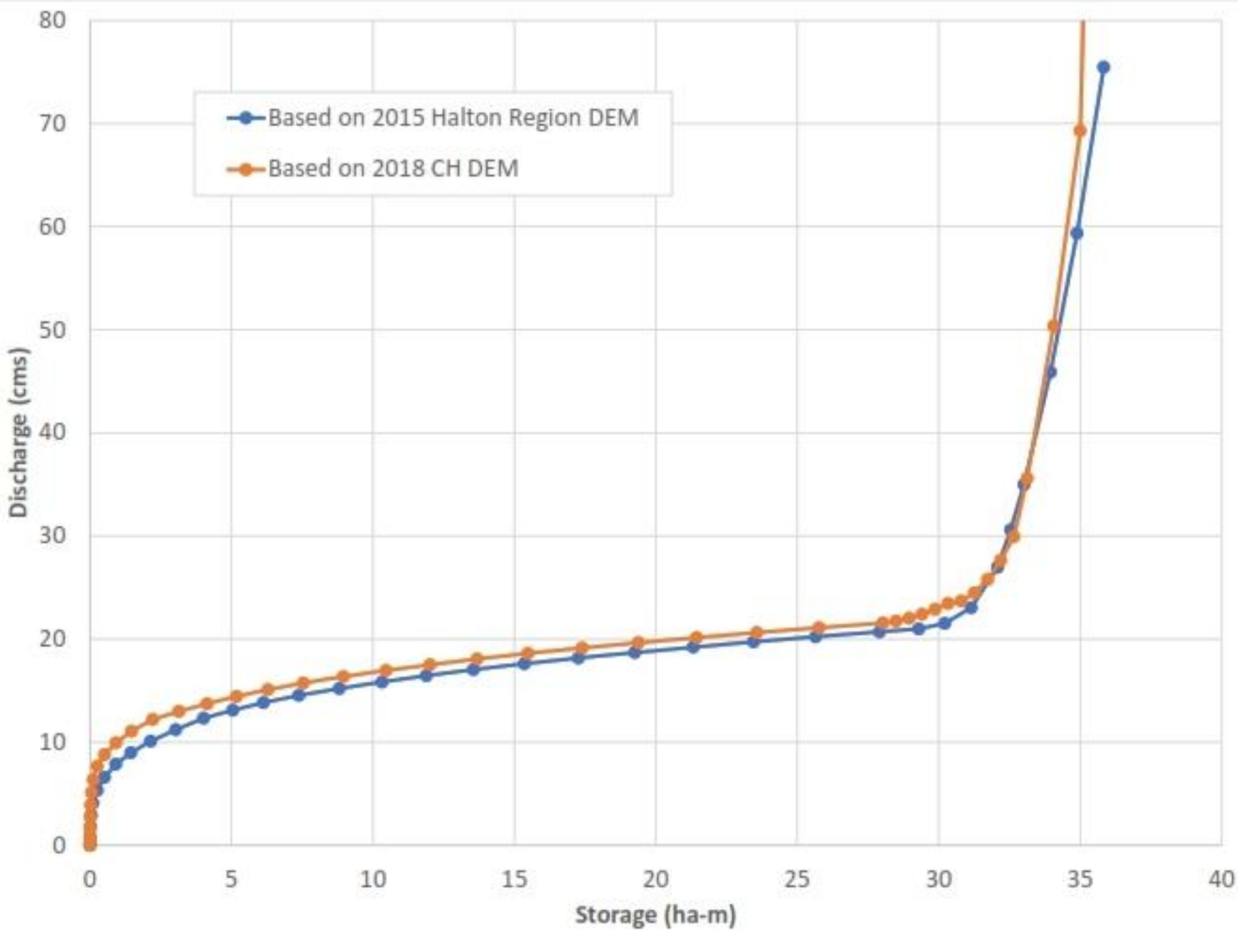

Figure 4.8: Storage-Discharge Rating Curve Comparison for Freeman Pond

Overall, the two rating curves presented in Figure 4.8 compare quite closely for the full extent of the curves. The updated (2018 CH DEM) rating curve indicates a slightly greater discharge for an equivalent storage (or conversely, a slightly reduced storage for the equivalent storage). This likely reflects the lower invert elevation of the primary box culvert outlet in the updated rating curve. The spillway portion of the curve appears generally consistent in both versions.

4.2.3 West Hager Pond

4.2.3.1 Base Rating Curve

The West Hager Pond is a smaller flood control facility (FCF) relative to the Freeman and East Rambo FCF, located north of the North Service Road between Skyway Drive and Kerns Road, along West Hager Creek (refer to Drawing 4). The facility is drained by a 1.8 m x 1.1 m box culvert (based on the City of Burlington's GIS database), with a constructed earthen berm to contain flows.

Given the limits of the previously described flood hazard scope for the Mobility Hub Study, the West Hager FCF was not reviewed or revised as part of the "Flood Hazard and Scoped Stormwater Management Assessment" (Wood, January 2020). The rating curve in the received/approved hydrologic modelling was left as received. The rating curve has been reviewed further as part of the current study, as described in Section 4.2.3.2.

4.2.3.2 Updated Rating Curve Development

A similar approach to that applied for the East Rambo and Freeman Flood Control Facilities (FCFs) has been applied to generate that for the West Hager FCF. As no topographic survey has been completed for the West Hager FCF (given that its function is much less critical to the current study area), the elevations of all features have been estimated based on the 2018 CH DEM. Based on this data source, an invert elevation of 109.41 m (CGVD2013) has been estimated.

A key consideration is the opening height of the control culvert. Record drawings (refer to Appendix A) suggest a 1.5 m x 1.6 m culvert, however the culvert has been field verified as having a width of 1.8 m, which is consistent with the City's database. The City's database indicates a height of 1.1 m. As noted, as part of the field inspection (Section 2), the culvert is partially filled with sediment, such that the effective opening height ranges between 0.8 m and 0.9 m. Two (2) scenarios have been considered accordingly for rating curve development: as per existing conditions (average effective opening height of 0.85 m), and assumed fully restored (opening height of 1.1 m; a more detailed investigation would be required to definitively confirm that the base of concrete is 1.1 m below the top). Consistent with the approach applied for the other two (2) FCFs, an approximation of MTO Design Chart 5.39 (inlet control of a box culvert) has been used to develop a stage-discharge relationship for these two (2) scenarios.

With respect to the overflow spillway, a section along the high point of the berm has been cut from the 2018 CH DEM. The section is irregular, with a lowest elevation of 115.57 m (CGVD2013), suggesting a maximum impoundment depth of approximately 6.16 m. Given the irregular nature of the spillway top, the section has been divided into multiple sub-sections, including additional spill sections at 115.65 and 115.88 m. Flow for each has been estimated based on equivalent trapezoidal sections, using Manning's Equation. The resulting combined stage-discharge for the individual sections has been summed, along with the stage-discharge relationship for the box culvert outlet, to develop a combined stage-discharge relationship. These data have then been combined with the stage-storage relationship to develop a combined storage-discharge relationship. Figure 4.9 presents a comparison of the original (previous SWMHYMO) rating curve, as well as two (2) versions of the updated (current) rating curve, based on the existing culvert sedimentation, and an assumed future clean-out version.

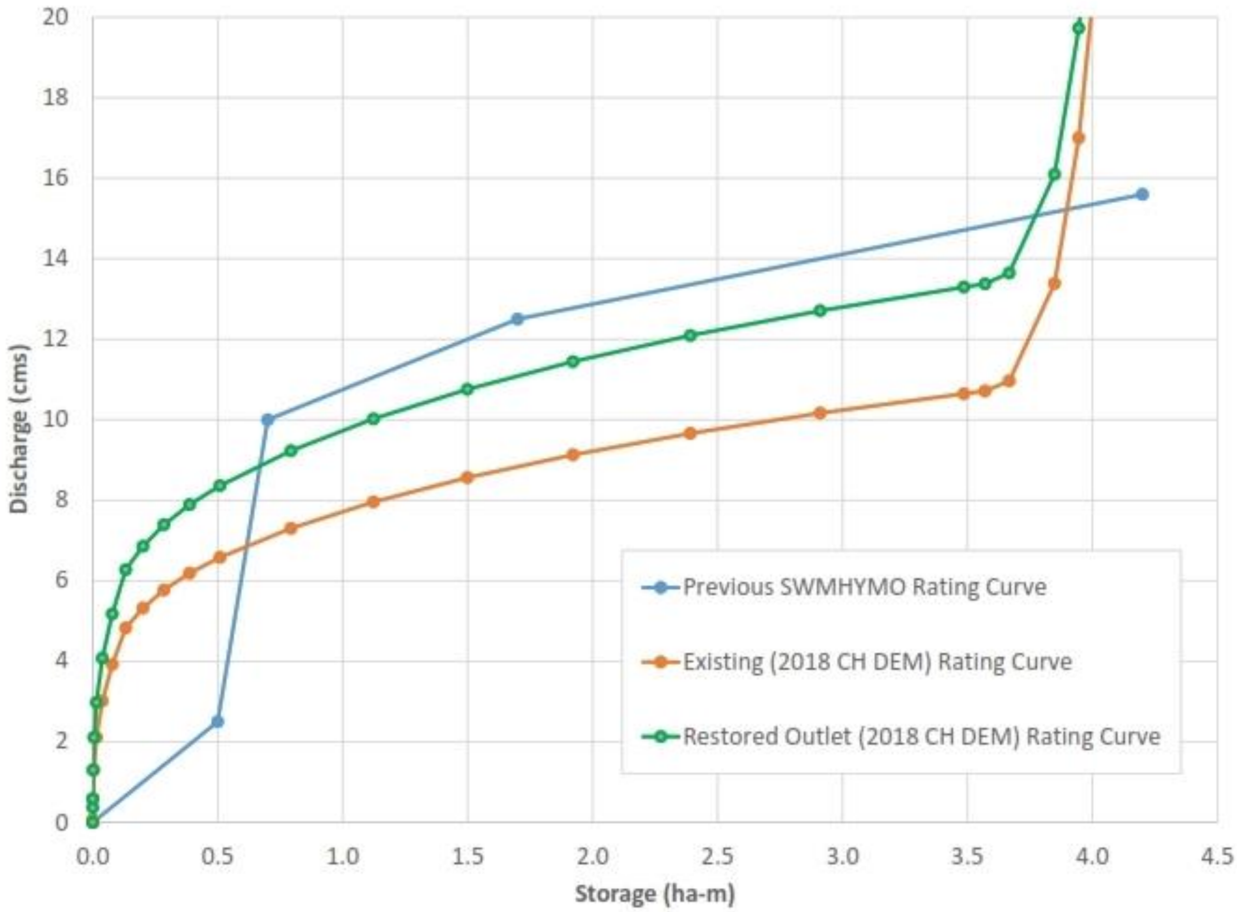

Figure 4.9: Storage-Discharge Rating Curve Comparison for West Hager Flood Control Facility

Neither of the updated rating curves indicate good agreement with the previous SWMHYMO rating curve the lower end; the basis for the step in the previous rating curve is unknown without reviewing the original design calculations. At higher (surcharge) elevations, the "restored outlet" scenario indicates reasonably good agreement with the previous curve, albeit a greater storage volume for an equivalent discharge (or conversely a decreased discharge for an equivalent storage volume). The previous rating curve also does not appear to have included any overflow component, likely because overtopping or spill was not expected as part of the previous hydrologic simulations. The impact of the reduced opening height of the box culvert due to sedimentation is clearly evident; discharges are notably reduced for an equivalent storage.

The impact of the updated/revised rating curves has been assessed further as part of the additional hydrologic simulation effort, as described in Section 4.3.

4.3 Base Modelling Results

4.3.1 Overall Hydrology

The currently approved hydrologic modelling for the Hager-Rambo system is the 1997 OTTHYMO model (ref. Philips Planning and Engineering, 1997). As part of the Urban Area Flood Vulnerability, Prioritization and Mitigation Study for the City of Burlington (in response to the August 4, 2014 storm event), Wood Environment & Infrastructure Solutions (Wood) updated the OTTHYMO model to a SWMHYMO format. As part of "Flood Hazard and Scoped Stormwater Management Assessment" (Wood, January 2020), a more detailed review and refinement of the SWMHYMO version of the model was completed, including making revisions and updates as required to more accurately represent current conditions.

In general, the completed hydrologic modelling update also included a re-parameterization of imperviousness for the subject study area (areas upstream of the study area remained unchanged). The City's Zoning Bylaw mapping was applied accordingly. Based on the above parameterization, an average overall impervious coverage of 74.6% +\- results for the existing drainage areas within the Burlington Mobility Hub Limit. The modelling updates have resulted in an increase of the impervious coverage from the original SWMHYMO modelling (which had an impervious coverage of approximately 70.6% +/-).

Drawing 5 presents the drainage area boundaries for the Upper Hager, Upper Rambo, and Roseland Creek systems, and also depicts key hydrologic nodes (locations) of interest based on the flows generated from the updated hydrologic modelling. Drawing 6 presents the updated hydrologic modelling schematic, based on the previously completed 1997 Study (Philips Planning and Engineering Ltd.).

It should be noted that as part of "Flood Hazard and Scoped Stormwater Management Assessment – Burlington GO Mobility Hub and Downtown" (Wood, January 8, 2020), two (2) scenarios were considered for the East Rambo Pond Flood Control Facility (FCF). Scenario 1 reflected a representation of existing conditions, including the associated spill via the CNR QEW underpass to West Rambo Creek (low flow discharge via the box culvert outlet and spill via the North Service Road would be expected to be directed to East Rambo Creek). Scenario 2 was an additional scenario, undertaken at the request of Conservation Halton, to assess the resulting flows if the spill via the CNR was eliminated (via a future retrofit) and all flows directed to the East Rambo Creek, as was (presumably) originally intended. Based on subsequent discussions with staff from the City of Burlington and Conservation Halton, a technical memorandum was prepared by Wood (ref. "East Rambo Flood Control Facility – Retrofit Feasibility Assessment", Scheckenberger/Senior-Dearlove/Brenner, December 18, 2019; a copy has been included in Appendix A). The technical memorandum concluded that a retrofit of the East Rambo FCF to prevent spill to the West Rambo was neither desirable (given the associated impacts to properties along East Rambo Creek) nor technically feasible (given the complexities and costs associated with re-directing additional flows across the Highway 403/QEW to East Rambo Creek). As such, all analyses in the current assessment are based on Scenario 1 only (i.e. East Rambo FCF as per existing spill flows).

It should also be noted that there is some uncertainty with respect to the preceding hydrologic modelling, which should be understood and acknowledged in the interpretation of the modelling results and in developing Official Plan/Land Use Policies. A key uncertainty with respect to hydrologic modelling is the estimation of imperviousness for different land uses. The values applied for areas within the Burlington GO Mobility are generally considered reasonable and appropriate, however it is noted that impervious coverage assumptions for external areas have not been re-evaluated. A detailed review of these values is considered beyond the scope of current study. Notwithstanding, a future overall hydrologic modelling review and update for the entire watershed (i.e. the Hager-Rambo system) is likely warranted, in particular to update the modelling from the somewhat dated SWMHYMO platform, but also to re-assess and re-evaluate overall subcatchment parameterization. This effort would be best combined with a field monitoring and data collection program (ideally 1 year or more) to collect actual flow response data at key locations within the respective subwatersheds, to adjust and calibrate/validate any revised estimates of imperviousness and associated land use parameterization. Such a study would be expected to proceed independently of any ongoing studies.

4.3.2 Without Flood Control Facilities (FCFs)

At the request of Conservation Halton, an additional scenario has been considered which involves the theoretical condition of the three (3) flood control facilities (FCFs) not being in place. The modelling results for this theoretical condition were previously included in "Flood Hazard and Scoped Stormwater Management Assessment, Burlington GO Mobility Hub and Downtown" (Wood, January 2020).

Extensive dialogue between Conservation Halton, the City of Burlington, and Wood has occurred regarding the inclusion (or not) of the approved flood control facilities in the assessment of flood risk. Ultimately, the City of Burlington has requested that these facilities be included in any assessment which will establish the limits of regulated areas at risk of flooding for land use planning purposes. The agreed upon condition for this directive related to the successful execution of this study, which focuses on the physical and functional conditions of the respective FCFs.

Notwithstanding, the City has agreed that as part of this study, an additional modelling scenario be conducted to assess the potential impact to simulated flows (and associated potential channel spills) due to the theoretical removal of these facilities. An updated hydrologic modelling scenario without the facilities in place has been undertaken by Wood accordingly. Simulated results are presented in Table 4.2.

Table 4.2 Simulated Peak Flow (m^3/s) for Hager-Rambo Diversion Channel Without Approved Flood Control Facilities in Place

Node	Current Drainage Area (ha)	Location	Simulated Peak Flow (m^3/s)	
			100-Year Storm (2004 IDF, 24H SCS)	Regional Storm
Q	642.6	East Rambo Pond Inlet	78.3	63.9
Q1	642.6	East Rambo Pond Box Culvert Outlet	18.9	18.6
Q2	642.6	East Rambo Pond Spill at CNR	46.5	41.3
Q3	642.6	East Rambo Pond Spill at North Service Road	13.0	4.0
J1	718.0	East Rambo Creek at CNR	35.1	35.7
J	736.5	East Rambo Creek at H-R Div Channel Conf.	37.5	38.6
P	84.1	West Rambo Creek at QEW	18.6	11.9
P3	116.7	West Rambo at CNR (South of Plains Road East)	69.1	52.4
P2	130.6	West Rambo at CNR (North of DePauls Lane)	71.1	54.1
P1	140.9	West Rambo Creek at Fairview	71.9	55.4
K	886.4	H-R Diversion Channel D/S of West Rambo	109.8	94.9
L	952.4	H-R Diversion Channel U/S of West Hager Conf.	115.9	102.8
G	661.6	Freeman Pond Inlet	77.4	71.0
G1	661.6	Freeman Pond Outlet	77.4	71.0
H1	155.0	West Hager Pond Inflow	18.1	18.1
H2	155.0	West Hager Pond Outflow	18.1	18.1
H	916.0	Freeman / West Hager Conf.	82.1	81.0
M	1,868.4	West Hager / H-R Diversion Channel Conf.	195.8	186.8
N	1,897.1	H-R Diversion Channel at Indian Creek	190.4	187.8

The results presented in Table 4.2 are provided for information purposes; these results have been compared to the results with the flood control facilities (FCFs) credited in subsequent sections, including analyzing the potential impacts on hydraulics.

4.3.3 With Flood Control Facilities (FCFs)

4.3.3.1 Base FCF Rating Curves

Peak Flows

As an initial analysis, hydrologic modelling results for the base Flood Control Facility (FCF) rating curves (as per "Flood Hazard and Scoped Stormwater Management Assessment – Burlington GO Mobility Hub and Downtown" (Wood, January 8, 2020) has been presented, as a basis of comparison to subsequent additional analyses completed for the current study.

As part of "Flood Hazard and Scoped Stormwater Management Assessment – Burlington GO Mobility Hub and Downtown" (Wood, January 8, 2020), analyses were based on the (unapproved) 2004 update to IDF data, along with a 24-Hour SCS Type II design storm distribution (which was determined to be the most critical temporal distribution). Notwithstanding, it is noted that the currently approved City IDF relationships (ref. 1999) are based on the data (RBG Gauge) from 1964 to 1990 which were approved in 1999. The 2004 values represent approximately a 5% increase in rainfall depths as compared to the 1999 values.

Simulated flows for key watercourse nodes are presented in Table 4.3 for the 100-year storm event and Regional Storm respectively; refer to Drawing 5 and 6 for node locations. Note that for the simulation of the Regional Storm, SCS Curve Numbers (CNs) have been updated to saturated (AMC-III) conditions to use the 12-hour version of Hurricane Hazel; depression storage values have also been set to zero.

Table 4.3 Simulated Peak Flows for Hager-Rambo Watershed – Base RC and 2004 IDF

Node	Drainage Area (ha)	Location	Simulated Peak Flow (m^3/s)	
			100-Year Storm (2004 IDF, 24H SCS)	Regional Storm
Q	642.6	East Rambo Pond Inlet	78.3	63.9
Q1	642.6	East Rambo Pond Box Culvert Outlet	17.2	18.5
Q2	642.6	East Rambo Pond Spill at CNR	21.1	39.4
Q3	642.6	East Rambo Pond Spill at North Service Road	0	2.2
J1	718.0	East Rambo Creek at CNR	21.2	32.8
J	736.5	East Rambo Creek at H-R Diversion Channel Conf.	25.5	35.6
P	84.1	West Rambo Creek at QEW	18.6	11.9
P3	116.7	West Rambo at CNR (South of Plains Road East)	30.1	49.0
P2	130.6	West Rambo at CNR (North of DePauls Lane)	30.9	50.6
P1	140.9	West Rambo Creek at Fairview	31.2	51.6
K	886.4	H-R Diversion Channel D/S of West Rambo Creek	53.6	86.7
L	952.4	H-R Diversion Channel U/S of West Hager Conf.	58.8	95.3
G	661.6	Freeman Pond Inlet	77.4	71.0
G1	661.6	Freeman Pond Outlet	17.4	43.6
H1	155.0	West Hager Pond Inflow	18.1	18.1
H2	155.0	West Hager Pond Outflow	11.3	14.4
H	916.0	Freeman / West Hager Conf.	33.2	65.4
M	1,868.4	West Hager / H-R Diversion Channel Conf.	91.6	146.3
N	1,897.1	H-R Diversion Channel at Indian Creek	91.5	146.9

A comparison of the simulated flows with FCF in place to those without FCF credited (as per Section 4.3.2) is presented in Table 4.4.

Table 4.4	Difference in Simulated Peak Flows for Hager-Rambo Watershed – Comparison of Results with and without FCFs Credited			
Node	Drainage Area (ha)	Location	Difference in Simulated Peak Flow (m^3/s)	
			100-Year Storm (2004 IDF, 24H SCS)	Regional Storm
Q	642.6	East Rambo Pond Inlet	0	0
Q1	642.6	East Rambo Pond Box Culvert Outlet	+1.7	+0.1
Q2	642.6	East Rambo Pond Spill at CNR	+25.4	+1.9
Q3	642.6	East Rambo Pond Spill at North Service Road	+13.0	+1.8
J1	718.0	East Rambo Creek at CNR	+13.9	+2.9
J	736.5	East Rambo Creek at H-R Diversion Channel Conf.	+12.0	+3.0
P	84.1	West Rambo Creek at QEW	0	0
P3	116.7	West Rambo at CNR (South of Plains Road East)	+39.0	+3.4
P2	130.6	West Rambo at CNR (North of DePauls Lane)	+40.2	+3.5
P1	140.9	West Rambo Creek at Fairview	+40.7	+3.8
K	886.4	H-R Diversion Channel D/S of West Rambo Creek	+56.2	+8.2
L	952.4	H-R Diversion Channel U/S of West Hager Conf.	+57.1	+7.5
G	661.6	Freeman Pond Inlet	0	0
G1	661.6	Freeman Pond Outlet	+60.0	+27.4
H1	155.0	West Hager Pond Inflow	0	0
H2	155.0	West Hager Pond Outflow	+6.8	+3.7
H	916.0	Freeman / West Hager Conf.	+48.9	+15.6
M	1,868.4	West Hager / H-R Diversion Channel Conf.	+104.2	+40.5
N	1,897.1	H-R Diversion Channel at Indian Creek	+98.9	+40.9

With respect to the 100-year storm event, notable increases in flows would be expected with the removal of the flood control facilities. Flows from the East Rambo FCF would increase, resulting in higher discharges to both East and West Rambo Creeks, given the flow split in this case. Flows to the Hager-Rambo Diversion channel downstream of West Rambo Creek (Brant/Fairview) would more than double in magnitude. Discharges from the Freeman FCF would increase more than four-fold, which demonstrates the attenuation performance of the Freeman FCF for the 100-year storm event. Discharges from the West Hager FCF would increase approximately 60% for the 100-year storm event. Beyond the confluence of the diversion channel and Hager Creek system, peak flows would be more than double those for the with flood control scenario.

With respect to the Regional Storm event, there would be a negligible impact due to removing the East Rambo FCF from the simulation. Box culvert outflows would increase by 1%, and CNR spills by 5%. While the percentage of increase in spills flows across the North Service Road is notable (82%), this reflects only a 1.8 m^3/s absolute increase in flow. As noted previously, the facility was not designed to provide any attenuation for the Regional Storm (100-year storm event design only). The currently simulated results also appear to be generally consistent with the Regional Storm flows presented in the previous (1997) reporting, which indicated generally no change in peak flows from upstream to downstream of the pond (suggesting no attenuative function for this event).

Discharges from the Freeman FCF would however be increased with its removal (63%), as would the West Hager FCF (26%), leading to corresponding increases of between 24 and 28% in West Hager Creek and the Hager-Rambo Diversion Channel downstream of the confluence with Hager Creek.

Based on the results presented in Table 4.4, it is notable that with flood control facilities removed, the 100-year storm event would in fact be the "regulatory" storm (i.e. peak flows are higher than those from the Regional Storm).

Flood Control Facilities

The performance of the flood control facilities for the 100-year and Regional Storm Events has also been reviewed; the modelling results are presented in Table 4.5. Note that all elevations are relative to the 1978 vertical datum, as this was the datum applied in the previous assessment (ref. "Flood Hazard and Scoped Stormwater Management Assessment – Burlington GO Mobility Hub and Downtown" (Wood, January 8, 2020)).

Table 4.5 Simulated Performance of Flood Control Facilities within Burlington Mobility Hub (as per Base FCF Rating Curves)

Facility	Storm Event	Peak Operating Level (m – 1978 Datum)	Peak Storage (m^3)	Total Outflow (m^3/s)	Discharge via Primary Outlet (m^3/s)	Spill Flow (m^3/s)
East Rambo	100-Year	106.13	156,900	38.3	17.2	21.1 (CNR) 0.0 (NSR)
	Regional	106.43	184,100	60.0	18.5	39.4 (CNR) 2.2 (NSR)
Freeman	100-Year	103.16	146,800	17.4	17.4	0
	Regional	105.38	337,500	43.6	21.9	21.7
West Hager	100-Year	NA	12,370	11.3	11.3	0
	Regional	NA	32,540	14.4	14.4	0

East Rambo FCF

With respect to the East Rambo Pond, the updated analysis indicates spill via the CNR for the 100-year storm event, as would be expected given the preceding discussion. For the 100-year storm event (2004 IDF data, 24 hour SCS Type II distribution), a maximum storage of 156,900 m^3 is indicated, which equates to a maximum water surface elevation of 106.13 m (well above the CNR railway elevation of 105.5 m +\-). The maximum discharge via the CNR QEW underpass would be 21.1 m^3/s. No spill across the North Service Road is indicated for the 100-year storm event (which would be expected to occur beginning approximately at 106.4 m +\-).

Based on the 2018 DEM/2020 survey updated rating curve for the East Rambo Pond, and the revised hydrologic modelling (including 2004 IDF-based design storms), modelling results indicate that spills from the East Rambo Pond to the CNR QEW underpass would be estimated to occur at the 10-year storm event (24 Hour SCS Type-II distribution) and greater.

For the Regional Storm event, a maximum simulated storage of 184,100 m^3 is indicated for the East Rambo Pond, which equates to a maximum water surface elevation of 106.43 m +\- (or above the North Service Road spill elevation). This would result in an estimated 2.2 m^3/s of spill across the North Service Road. The maximum simulated spill discharge via the CNR QEW underpass is 39.4 m^3/s, while 18.5 m^3/s would be discharged via the primary culvert outlet. The simulated CNR QEW underpass spill is notably substantial and would be expected to have an impact to downstream receivers.

Freeman FCF

The updated simulated results for the Freeman Pond (Table 4.5) indicate that the 100-year flow is easily contained by the facility (maximum operating level of 103.16 m), with all discharge via the primary outlet.

For the Regional Storm Event, the revised modelling indicates a peak operating level of 105.38 m, which would be greater than the estimated spill elevation of 104.90 m. An estimated spill of 21.7 m^3/s over the berm therefore results, which is approximately equivalent to the simulated discharge from the primary culvert outlet (21.9 m^3/s). As noted with respect to the pond (Section 2.1.2.2), the currently available topographic data indicate that spill may occur at other locations (on the east side of the facility - beyond the primary spillway) beginning at approximately 105.2 m +\- (i.e. less than the simulated maximum Regional Storm operating level of 105.38 m). No further analyses of these potential secondary spills has been included in the current assessment. Similar to the observations with respect to the East Rambo Pond, it is noted that the hydrologic modelling is not calibrated, thus there may be a benefit to undertaking such an effort as part of a follow-up study, to better assess the potential flood risk in this area as noted.

West Hager FCF

The simulated results indicate that the West Hager FCF would not be expected to spill for either the 100-year or Regional Storm Event, based on the originally approved SWMHYMO modelling rating curve. The maximum ordinate of the FCF is nearly reached under the Regional Storm Event (i.e. 15.6 m^3/s), however is not exceeded.

The corresponding water surface elevation cannot be estimated, given that the original stage-storage-discharge rating curve is not available.

4.3.3.2 Updated FCF Rating Curves

The preceding hydrologic modelling for the Hager-Rambo watershed has been re-simulated using the updated flood control facility (FCF) rating curves described in Section 4.2, specifically using the more current (2018) DEM provided by Conservation Halton (CH), as well as the supplementary topographic survey completed by Wood for this study (2020) Simulated peak flows for the 100-year (2004 IDF, 24H SCS distribution as previously employed) storm event and the Regional Storm using these updated rating curves are presented in Table 4.6. The "restored outlet" rating curve has been applied for the West Hager FCF (refer to Section 4.2.3.2), under the assumption that either the accumulated sediment would be washed out during a formative storm event, or that the City of Burlington will endeavor to clean out the accumulated sediment and restore full culvert capacity in the short-term.

The simulated results indicate that in general, the updated FCF rating curves have a nominal difference to simulated peak flows along downstream watercourses. For the 100-year storm event, localized peak flow increases are indicated for the spill from the East Rambo FCF to West Rambo Creek via the CNR QEW underpass, and also a local increase in peak flows to the Hager-Rambo Diversion channel, however this increase is mitigated by the time the channel confluences with the West Hager Creek (i.e. discharge from Freeman and West Hager FCF). The Freeman FCF itself indicates a slightly higher peak flow for the 100-year Storm Event, while the West Hager FCF indicates a decrease for the same event. Other locations indicate no change, or typically decreases.

For the Regional Storm Event, the majority of the reporting locations indicate decreases in peak flows with the exception of one very minor simulated increase (0.1 m^3/s) for the West Rambo Creek at Fairview Street. The Regional Storm has a lower peak flow at the East Rambo FCF, however a greater overall volume, as compared to the 100-year Storm Event. A slightly increased discharge of spill via the CNR QEW underpass is again indicated as compared to the previous FCF rating curve, however this is balanced by a decrease in spill via the North Service Road, given the higher estimated spill elevation. This results in a decrease in overall flows to East Rambo Creek, and overall, no change in Regional Storm peak flows within the Hager-Rambo Diversion Channel. Reduced discharges from the Freeman and West Hager FCFs are again indicated.

Overall, the updated results for the Regional Storm Event (the governing, or regulatory storm as compared to the 100-year Storm Event) with the updated FCF rating curves indicates the same, or reduced peak flows as compared to the results presented in "Flood Hazard and Scoped Stormwater Management Assessment – Burlington GO Mobility Hub and Downtown" (Wood, January 8, 2020). The two (2) minor increases in flows are localized to specific areas and are minor changes, and do not warrant any updating of hydraulic modelling (to assess flooding extents) as part of the current study.

Specific metrics for each of the Flood Control Facilities (FCFs) are provided in Tables 4.7, 4.8, and 4.9 for the East Rambo, Freeman, and West Hager FCFs respectively.

Table 4.6 Simulated Peak Flows (m^3/s) for Hager-Rambo Watershed – Updated FCF Rating Curve

Node	Current Drainage Area[1] (ha)	Location	Updated Rating Curves		Difference from Previous Rating Curves	
			100-Year Storm (2004 IDF, 24H SCS)	Regional Storm	100-Year Storm (2004 IDF, 24H SCS)	Regional Storm
Q	642.6	East Rambo Pond Inlet	78.3	63.9	0	0
Q1	642.6	East Rambo Pond Box Culvert Outlet	17.2	18.5	0	0
Q2	642.6	East Rambo Pond Spill at CNR	22.4	39.9	+1.3	+0.5
Q3	642.6	East Rambo Pond Spill at North Service Road	0	0	0	-2.2
J1	718.0	East Rambo Creek at CNR	21.2	31.6	0	-1.2
J	736.5	East Rambo Creek at H-R Diversion Channel Conf.	25.5	34.6	0	-1.0
P	84.1	West Rambo Creek at QEW	18.6	11.9	0	0
P3	116.7	West Rambo at CNR (South of Plains Road East)	31.8	49.0	+1.7	0
P2	130.6	West Rambo at CNR (North of DePauls Lane)	32.8	50.6	+1.9	0
P1	140.9	West Rambo Creek at Fairview	33.2	51.7	+2.0	+0.1
K	886.4	H-R Diversion Channel D/S of West Rambo Creek	55.6	86.7	+2.0	0
L	952.4	H-R Diversion Channel U/S of West Hager Conf.	61.0	94.4	+2.2	-0.9
G	661.6	Freeman Pond Inlet	77.4	71.0	0	0
G1	661.6	Freeman Pond Outlet	18.2	38.1	+0.8	-5.5
H1	155.0	West Hager Pond Inflow	18.1	18.1	0	0
H2	155.0	West Hager Pond Outflow	10.1	14.0	-1.2	-0.4
H	916.0	Freeman / West Hager Conf.	30.2	58.6	-3.0	-6.8
M	1,868.4	West Hager / H-R Diversion Channel Conf.	89.2	137.8	-2.4	-8.5
N	1,897.1	H-R Diversion Channel at Indian Creek	89.6	140.4	-1.9	-6.5

Table 4.7	Simulated Performance of East Rambo FCF					
Metric	100-Year Storm			Regional Storm		
	Base RC	Updated RC	Difference	Base RC	Updated RC	Difference
Peak Operating Level (m – 1978 Datum)	106.13	106.11	-0.02	106.43	106.44	+0.01
Peak Storage (m^3)	156,900	153,400	-3,500	184,100	180,500	-3,600
Total Outflow (m^3/s)	38.3	39.6	+1.3	60.0	58.4	-1.6
Discharge via Primary Outlet (m^3/s)	17.2	17.2	0	18.5	18.5	0
Spill Flow (m^3/s)	21.1 (CNR) 0 (NSR)	22.4 (CNR) 0 (NSR)	+1.3 (CNR) 0 (NSR)	39.4 (CNR) 2.2 (NSR)	39.9 (CNR) 0 (NSR)	+0.5 (CNR) -2.2 (NSR)

Table 4.8	Simulated Performance of Freeman FCF					
Metric	100-Year Storm			Regional Storm		
	Base RC	Updated RC	Difference	Base RC	Updated RC	Difference
Peak Operating Level (m – 1978 Datum)	103.16	102.97	-0.19	105.38	105.24	-0.14
Peak Storage (m^3)	146,800	140,000	-6,800	337,500	332,900	-4,600
Total Outflow (m^3/s)	17.4	18.2	+0.8	43.6	38.1	-5.5
Discharge via Primary Outlet (m^3/s)	17.4	18.2	+0.8	21.9	22.5	+0.6
Spill Flow (m^3/s)	0	0	0	21.7	15.6	-6.1

Table 4.9	Simulated Performance of West Hager FCF					
Metric	100-Year Storm			Regional Storm		
	Base RC	Updated RC	Difference	Base RC	Updated RC	Difference
Peak Operating Level (m – 1978 Datum)	NA	113.51	NA	NA	116.10	NA
Peak Storage (m^3)	12,370	11,900	-470	32,540	36,990	+4,450
Total Outflow (m^3/s)	11.3	10.1	-1.2	14.4	14.0	-0.4
Discharge via Primary Outlet (m^3/s)	11.3	10.1	-1.2	14.4	13.5	-0.9
Spill Flow (m^3/s)	0	0	0	0	0.5	+0.5

East Rambo FCF

With respect to the East Rambo FCF, operating levels are generally similar to those previously estimated, however storage volumes are slightly less. Changes in simulated peak discharges vary depending on the storm event under consideration. For the 100-year storm event, there is an increase in overall peak discharge, which is attributable to increased spill via the CNR QEW underpass, as the simulated discharge via the primary outlet (box culvert outlet) remains unchanged. For the Regional Storm Event, overall discharge is in fact decreased; primary discharge remains unchanged (box culvert outlet) however CNR QEW underpass spill is again slightly increased. This is counter-balanced however by a reduction in discharge in spill via the North Service Road (no simulated spill occurs) due to the higher simulated spill elevation in this case.

Freeman FCF

With respect to the Freeman FCF, operating levels and storage volumes are consistently reduced as compared to the previous scenario. This is considered attributable to the revised outlet invert, which is lower by some 0.53 m as compared to the previously estimated value (refer to Table 4.1). Conversely, this results in a larger discharge for approximately the same operating level, as the outlet control structure (box culvert) has a relatively higher head given the lower invert. This is why a slightly higher peak flow is indicated for the 100-year storm event, which involves only box culvert discharge. For the Regional Storm, discharge via the box culvert outlet is again slightly increased due to the higher head. However, overall discharge is decreased due to the estimated reduction in spill flow via the overflow spillway. This is attributable to the overflow spillway. Although the spill elevation is estimated to occur at 104.68 m (1978 datum) in the revised rating curve, as compared to 104.90 m in the original rating curve, this is countered by the estimated shape of the spillway geometry, and differences in the two combined storage-discharge rating curves at spill elevations.

West Hager FCF

The updated rating curve for the West Hager FCF (assuming the "restored" scenario of clean-out or scour of sedimentation within the culvert as noted previously) results in slightly reduced discharges and storage for the 100-year storm event. For the Regional Storm Event, the updated rating curve indicates a greater degree of storage, and a decreased overall discharge. However, the net change in discharge represents a decreased flow rate via the box culvert outlet, and a very minor spill via the spillway (0.5 m^3/s, or a depth of overtopping of approximately 0.1 m (spill elevation of 116.0 m +\-, simulated peak Regional Storm water surface elevation of 116.10 m).

4.3.3.3 Spill Impacts

As per comments received from Conservation Halton (August 27, 2020), it is understood that confirmation is required that all embankments for the FCFs remain stable under spill conditions. A review of spill conditions has been prepared, based on the results presented in Tables 4.7 to 4.9 (Updated FCF Rating Curves), and the nature of each of the FCFs.

East Rambo FCF

For the East Rambo FCF, there is no defined spillway as the facility is essentially below existing ground (excavated) without an embankment. Further, overtopping was not included as part of the original design considerations. The results presented in Table 4.7 indicate that under the Regional Storm Event, spill would only be expected to occur via the CNR underpass, no spill is expected via the North Service Road (NSR). There is no embankment or berm between the primary area of the FCF and CNR underpass. In the event of a debris blockage or storm event greater than the Regional Storm Event, some spill via the overtopping of the NSR would be expected southerly over the NSR to the QEW. As noted, the topography in this area is not considered to be an embankment, given the sunken nature of the FCF, and therefore stability under spill conditions is not considered to be a concern. No formal calculations have been completed given this context and field condition.

Freeman FCF

For the Freeman FCF, a spillway has been graded into the top of the berm in the vicinity of the outlet control structure. As per Table 4.8, for the Regional Storm Event, a spill of 15.6 m^3/s (updated FCF rating curve) is expected, at an elevation of 105.24 m (1978 datum) or 104.82 m (CGVD2013). This spill would occur primarily via the primary spillway, however as per the surveyed and verified grades in the vicinity of the FCF (refer to Table 2.1), a minor amount of spill would also be expected to occur via the low point along the QEW off-ramp to Brant Street (estimated spill elevation of 104.75 m (CGVD2013) or 105.17 m (1978)). This secondary location represents a nominal maximum spill depth of 0.07 m (0.17 m^3/s). This nominal amount would not be expected to have any impact on the adjacent grades or stability of the off-ramp asphalt.

The primary spill would therefore occur via the spillway as noted. The maximum Regional Storm elevation would represent a maximum depth of 0.57 m above the lowest elevation along the fence line (104.25 m (CGVD2013) or 104.67 m (1978)), with a total top width of 120 m. While the maximum estimated spill depth would be 0.57 m, given the grading of the spillway top, the average overtopping depth over the 120 m spill width would be less, approximately 0.22 m. Approximately 46% of the total estimated spill flow would occur at the primary spillway area (13 m wide area), with an estimated localized peak flow of 7.2 m^3/s in this area (the balance would occur via shallower spill via the remaining portion of the spillway). As such, erosion risk to embankment stability would be expected to be the greatest in this area. Based on the available DEM, the embankment slope is at approximately a grade of 3H:1V, or 30%. Based on this grade, a peak flow of 7.2 m^3/s, and a spill width of 13 m, and a Manning's Roughness Coefficient of 0.035 (smooth grass – dense vegetation may actually be higher than this value), a flow depth of 0.14 m along the slope would be expected, with a corresponding surface velocity of 4.1 m/s. Although the embankment slope is well vegetated, this would exceed the typical expected erosive resistance for vegetation (which is generally up to 2 m/s as per Design Chart 2.17 from the MTO Drainage Management Manual). Notwithstanding, given the infrequency of spill (Regional Storm Event only), the expected short duration of spill, and the dimensions of the embankment (approximate 6 m top width), the erosion risk to embankment stability from spill flow is considered low. That said, the City may consider reviewing the spillway further as part of its on-going repair/improvement work with Ch and others, and determine if any supplementary stability works (grading modifications, rip-rap placement, embankment liner, etcetera) is warranted in this area.

West Hager FCF

For the West Hager FCF, there is no defined spillway and overtopping was not included as part of the original design considerations. The simulated results (Table 4.9) indicate that only a nominal spill of 0.5 m^3/s is indicated under the Regional Storm Event. An increased spill is possible in the event of a blocked low flow outlet or a higher magnitude storm, however this is considered unlikely based on the operational history of this FCF over the past 25 years +\- which has shown that blockage is not a high risk mechanism. Based on the simulated results and the developed rating curve, for the Regional Storm Event, the estimated spill would occur over a width of approximately 20 m, at a maximum overtopping depth of 0.11 m (average depth would be less). Given the shallow depth and wide spill width, concentrated erosion would not be a concern with respect to berm stability. Further, based on the completed site reconnaissance, the existing slope is well vegetated which is expected to remain table under short-term overtopping as described in the foregoing.

4.3.4 Hydraulic Modelling Results

Hydraulic modelling (HEC-RAS) was completed for the open watercourses within the Burlington GO Mobility Hub (Hager-Rambo system) as part of "Flood Hazard and Scoped Stormwater Management Assessment – Burlington GO Mobility Hub and Downtown" (Wood, January 2020). Further details on hydraulic model development are provided in that document. Flood hazard mapping (based on the crediting of the three (3) subject FCFs) is also provided as part of this document.

As part of the current assessment, the relative impacts of the three (3) flood control facilities (FCFs) on flooding extents has been assessed. It is not considered warranted to re-generate updated flood hazard mapping for the alternative scenarios; rather a scoped effort considering key hydraulic modelling outputs (simulated depth and estimated top width of floodplain extents) have been completed. Given the relative nominal change in estimated peak flows with the revised FCF rating curves in place (Table 4.6) it is not considered necessary to assess the changes in generated flood hazard limits with the revised flows in place, as the associated changes are also expected to be nominal. Based on discussions with CH staff however (ref. May 26, 2020), it is understood that there is some interest in assessing the potential differences in flooding extents associated with not crediting the three (3) FCFs in this area. A further hydraulic analysis related to a sensitivity analysis (premised primarily on the expected impacts of climate change with due consideration of other uncertainties) has been completed separately, and is presented in Section 4.4.3.

In order to summarize the hydraulic modelling results, simulated values have been grouped by primary reaches of interest. These include:

- East Rambo Creek (Plain Road to Brant Street)
- West Rambo Creek (Leighland Road to Fairview Street)
- Upper Hager-Rambo Diversion Channel (West Rambo Creek to Hager Creek)
- Hager Creek (Freeman Pond to Hager Creek)
- Lower Hager-Rambo Diversion Channel (Hager Creek to Indian Creek)

It should be noted that the developed hydraulic model (HEC-RAS) was based on the flows presented in "Flood Hazard and Scoped Stormwater Management Assessment – Burlington GO Mobility Hub and Downtown" (Wood, January 2020). As evident from Table 4.4, the peak flows associated with non-crediting of the three (3) FCFs are considerably higher. As such, it would logically be expected that hydraulic cross-sections would be exceeded, and wider floodplain extents (and potential spills) would occur. Any such impacts have not been assessed as part of the current analysis; the existing model geometry remains unchanged in all flow scenarios. The results should therefore be understood as limited, and are provided as a general indication of the range in potential differences in riverine flooding extents.

Results are presented in Table 4.10 through 4.12 for the 100-year storm event (SCS Type II storm, 2004 IDF), and in Tables 4.13 through 4.15 for the Regional Storm Event (Hurricane Hazel).

Table 4.10 Summarized Hydraulic Modelling (HEC-RAS) Results with FCF credited (100-Year Storm – Original FCF Rating Curves)

Reach	Length (m)	Depth (m)			Top Width (m)		
		Min	Max	Mean	Min	Max	Mean
East Rambo Creek	1,495	1.34	2.98	2.01	6.07	267.43	31.03
West Rambo Creek	575	1.51	5.00	2.95	6.00	423.68	109.47
Upper Hager-Rambo Diversion Channel	740	1.99	3.54	2.78	10.17	23.36	16.82
Hager Creek	1,320	2.16	5.31	3.26	4.53	410.02	48.23
Lower Hager-Rambo Diversion Channel	845	2.37	3.35	2.76	10.65	19.02	15.66

Table 4.11 Summarized Hydraulic Modelling (HEC-RAS) Results without FCF credited (100-Year Storm)

Reach	Length (m)	Depth (m)			Top Width (m)		
		Min	Max	Mean	Min	Max	Mean
East Rambo Creek	1,495	1.83	4.87	3.05	7.01	1,098.34	104.77
West Rambo Creek	575	2.35	5.38	3.82	6.50	435.12	137.34
Upper Hager-Rambo Diversion Channel	740	3.87	5.33	4.72	12.45	92.89	38.21
Hager Creek	1,320	3.54	7.31	4.94	6.64	450.54	220.65
Lower Hager-Rambo Diversion Channel	845	3.51	5.41	4.40	15.39	111.51	49.57

Table 4.12 Difference in Summarized Hydraulic Modelling (HEC-RAS) Results with and without FCF credited (100-Year Storm)

Reach	Length (m)	Difference in Depth (m)			Difference in Top Width (m)		
		Min	Max	Mean	Min	Max	Mean
East Rambo Creek	1,495	+0.49	+1.89	+1.04	+0.94	+830.91	+73.74
West Rambo Creek	575	+0.84	+0.38	+0.87	+0.50	+11.44	+27.87
Upper Hager-Rambo Diversion Channel	740	+1.88	+1.79	+1.94	+2.28	+69.53	+21.39
Hager Creek	1,320	+1.38	+2.00	+1.68	+2.11	+40.52	+172.43
Lower Hager-Rambo Diversion Channel	845	+1.14	+2.06	+1.65	+4.74	+92.49	+33.91

Table 4.13 Summarized Hydraulic Modelling (HEC-RAS) Results with FCF credited (Regional Storm – Original FCF Rating Curves)

Reach	Length (m)	Depth (m)			Top Width (m)		
		Min	Max	Mean	Min	Max	Mean
East Rambo Creek	1,495	1.81	4.48	2.94	6.99	1,098.34	101.21
West Rambo Creek	575	2.00	5.19	3.49	6.46	431.74	126.21
Upper Hager-Rambo Diversion Channel	740	2.91	5.02	4.04	11.07	84.37	31.00
Hager Creek	1,320	3.32	7.05	4.67	6.47	449.76	203.69
Lower Hager-Rambo Diversion Channel	845	3.09	4.52	3.73	12.26	90.62	30.44

Table 4.14 Summarized Hydraulic Modelling (HEC-RAS) Results without FCF credited (Regional Storm)

Reach	Length (m)	Depth (m)			Top Width (m)		
		Min	Max	Mean	Min	Max	Mean
East Rambo Creek	1,495	1.81	4.65	3.02	6.99	929.06	88.97
West Rambo Creek	575	2.06	5.22	3.58	6.49	431.95	127.39
Upper Hager-Rambo Diversion Channel	740	3.77	5.19	4.56	12.25	88.45	36.57
Hager Creek	1,320	3.40	7.18	4.83	6.42	450.15	211.24
Lower Hager-Rambo Diversion Channel	845	3.49	5.23	4.33	1500	108.79	46.16

Table 4.15 Difference in Summarized Hydraulic Modelling (HEC-RAS) Results with and without FCF credited (Regional Storm)

Reach	Length (m)	Difference in Depth (m)			Difference in Top Width (m)		
		Min	Max	Mean	Min	Max	Mean
East Rambo Creek	1,495	0	+0.17	+0.08	0	-169.28	-12.24
West Rambo Creek	575	+0.06	+0.03	+0.09	+0.03	+0.21	+1.19
Upper Hager-Rambo Diversion Channel	740	+0.86	+0.17	+0.53	+1.18	+4.08	+5.57
Hager Creek	1,320	+0.08	+0.13	+0.16	-0.05	+0.39	+7.55
Lower Hager-Rambo Diversion Channel	845	+0.40	+0.71	+0.60	+2.74	+18.17	+15.72

For the 100-year storm event, the simulated results suggest a general sensitivity to the removal of FCFs and the associated large increase in simulated flows presented previously. Average water surface elevation increase of 1 -2 m are indicated, and average floodplain top width increases of between 20 and 70 m for the majority of the watercourses in the subject area (although localized areas would be expected to have greater increases, as indicated by the maximum values presented). Overall, Hager Creek indicates the greatest sensitivity to the removal of the three (3) FCFs for the 100-year storm event, which likely reflects its location directly downstream of the two (2) of the FCFs (Freeman and West Hager), as well as the generally confined nature of the channel system in this area.

For the Regional Storm, the simulated results indicate a reduced sensitivity to the removal of the FCFs, with simulated differences consistently lower than those for the 100-year storm event. Average water surface elevation increases of between 0.08 and 0.60 m are indicated, with average floodplain top width increases consistently less than 15 m. The reduced impacts for West and East Rambo Creeks are logical, given the previous observations with respect to the East Rambo FCF (i.e. that it does not provide Regional Storm control and thus its impacts for this event is minimal whether or not it is included). The greatest impacts for the Regional Storm are indicated for the primary Hager-Rambo Diversion channel, with average simulated water level increases of approximately 0.5 m.

It should be noted again that the preceding analysis is greatly simplified for the assessment of the higher simulated flows associated with the removal of the three (3) FCFs. In particular, the preceding does not consider spill flows, which would be expected along Fairview Street and the Hager-Rambo Diversion Channel. The potential increased flows and associated impacts to the Downtown area have not been assessed further as part of the current hypothetical analyses.

4.4 Sensitivity Analysis

4.4.1 Approach

Further to consultation with City of Burlington and Conservation Halton over the course of the flood risk assessments, it is understood as part of the current study, Conservation Halton requires a sensitivity analysis focused on the potential impacts on the infrastructure’s performance due to hydrologic and hydraulic uncertainty.

There are numerous factors considered in the hydrologic modelling which may introduce uncertainty into the modelling and associated results. Some of these potential factors include:

- Future changes in land use within the watershed
- Changes in hydrologic model parameterization in the future (due to the availability of suitable calibration data, or future review and hydrologic modelling update study)
- Changes in approved/recommended hydrologic modelling approaches or techniques
- Future changes in climate patterns, including severe rainfall events

In addition, there are potential physical factors with respect to the flood control facilities (FCFs) themselves which may affect their sensitivity to changes in flows, including factors such as a propensity for debris blockage, or the physical, structural, and geotechnical stability of the FCFs themselves. These factors are considered to have been generally addressed through the field visits and analyses summarized in the previous sections, which have concluded that the three (3) FCFs are in sound physical condition. As noted previously, the 3 FCFs are also not considered to be prone to debris blockage based on the 25+ years of continued operation, and the nature of the FCFs themselves (larger facilities with correspondingly larger outlets which are less prone to blockage). Further, it is difficult to quantify a reasonable assumption with respect to debris blockage (how much debris, where, when would it release, etcetera) and the corresponding modelling results are equally uncertain. As such, the current sensitivity analysis has focused on hydrologic sensitivity.

Rather than analyzing multiple hydrologic variables, it is considered that a general sensitivity analysis, one that considers the general impact of potential increases in flows within the watershed (which could result from any of the previously noted hydrologic factors) is appropriate. Given the uncertainty associated with potential future or revisited land use coverage, it is considered such a sensitivity analysis is best completed on the basis of potential changes in rainfall patterns associated with climate change, which represents a surrogate for all other uncertainties cited above.

The current uncertainty analysis has focused upon the assessment of uncertainty with all three (3) flood control facilities (FCFs) credited in the analyses. CH staff (ref. May 26, 2020 discussion) has provided its opinion that hydrologic and hydraulic modelling (and associated flooding extents) results may exhibit different relative sensitivity depending on whether or not the FCFs are credited or not. In general, it is understood that CH is of the opinion that impacts will likely be relatively more sensitive for the modelling with the FCFs credited than with their theoretical removal, given that overall flood extents for the scenario with the FCFs not credited would be comparably much higher (consistent with the analyses presented previously in Section 4.3.4), and thus the incremental change comparably lower. Although the current analyses have focused on a scenario with the crediting of the three (3) FCFs (which as noted is expected to be relatively more sensitive), the potential relative sensitivity of these two scenarios and the associated potential impact of crediting (or not crediting) of the FCF functions in the hydrologic modelling should be acknowledged and understood. Of note is that each of the FCF has a freeboard inherent in the design, and if the uncertainty is within this freeboard allowance there would be a nominal change to off-site flows and risk. If, however the freeboard is exceeded the reverse could be anticipated. Hence the level of uncertainty would also affect the potential off-site influence.

Based on the preceding, Wood has conducted research into various other jurisdictions who have conducted assessments of long-term impacts to precipitation due to climate change.

The key parameters to consider include:

- Greenhouse Gas Emissions Scenario (Representative Concentration Pathways – RCP)
- Projected Period Timeframe
- Statistical Distribution

Based on recent work by Wood (ref. "Review of Future Rainfall Scenarios, Town of Oakville", December 2018), approximately 89 scenarios were reviewed and assessed with varying numerics associated with the foregoing (ref. Appendix C). Premised on this assessment, Wood and the Town of Oakville agreed on the following:

<u>RCP</u>

Scenario RCP 4.5 was selected as the preferred scenario given its "moderate" uptake of climate change mitigation. Albeit, it was suggested that system stressing consider higher less aggressive uptake of mitigation (RCP 6.0 or 8.5) to assess vulnerability but not direct design efforts (ref. attachments/excerpts in Appendix C).

Time Period/Framework

Most temporal projections are between 30 and 60 years (+/- 10 years) with available tools. It was considered appropriate to use a projection to 2080 given the likelihood for built infrastructure to extend to at least this time period based on its engineered life.

Statistical Distribution

Recent projection tools (University of Western) have updated their statistical distribution from Gumbel to GEV. Others such as the ECCC Tool and Ontario Climate Data Portal have continued to apply the Gumbel technique. Based on various uncertainties in ultimate adoption of a preferred statistical distribution, the Town of Oakville will continue the use of Gumbel, while monitoring developments in this regard.

Based on the foregoing, the Oakville study established the following based on a compendium of various available tools/methodologies, RCP=4.5, timeframe to 2080 and Gumbel distribution:

Table 4.16: Comparison of Rainfall Depths

Event Frequency (years)	24-Hour Rainfall Depth (mm)		% Difference
	Present Day	2080's RCP 4.5	
5	59.7	80.0	34%
100	96.4	132.5	37%

Other jurisdictions have conducted similar assessments of varying complexities, while others have merely arbitrarily set a percentage change to IDF depths. The following summarizes comparisons amongst various municipalities.

Table 4.17: Comparison of Municipal Rainfall Adjustments

Municipality	Methodology	Target Year	% Change	
			5 yr.	100 yr.
Welland	Analytical	TBD	ongoing	ongoing
Barrie	% Shift	N/A	15%	15%
Ottawa	% Shift	N/A	20%	20%

Based on the foregoing, it is proposed to modify the IDF for the 100 yr. by 35%, as this in the opinion of Wood, represents a significant and supportable projection for use in a sensitivity assessment. It should be noted that this adjustment is for the return period events only and not the Regional Storm (Hurricane Hazel) as no adjustment factor exists in the industry associated with this event.

4.4.2 Hydrologic Simulation Results

For the purposes of the current study, the sensitivity analysis of hydrologic simulation results has been based on the modelling results presented in Section 4.3.3, namely with FCF facilities credited and included, for the reasons discussed previously.

The hydrologic modelling has been re-run for the climate change adjusted 100-year event. All ordinates of the 100-Year Storm Event (2004 IDF update 24-Hour SCS Type II distribution) have been updated uniformly by 35%. The modelling has been re-simulated using this updated storm event in order to assess the sensitivity of model outputs (primarily related to peak flows at nodes of interest and the performance of the three (3) flood control facilities). The results have been generated both on the basis of the original FCF rating curves (as per "Flood Hazard and Scoped Stormwater Management Assessment – Burlington GO Mobility Hub and Downtown" (Wood, January 8, 2020)), as well as the updated rating curves generated as part of the current study, based on the 2018 CH DEM, as well as scoped topographic survey completed by Wood (2020). Peak flows at key nodes of interest are presented in Tables 4.18 and 4.19 for the two rating curve approaches respectively, along with a comparison to the base (non climate-change adjusted) IDF presented in Section 4.2.

Table 4.18 Simulated Peak Flows for Hager-Rambo Watershed – Sensitivity Analysis (Original FCF Rating Curves)

Node	Current Drainage Area (ha)	Location	Simulated Peak Flow (m^3/s)		
			Adjusted 100-Year Storm	Difference from Base IDF	Difference (%)
Q	642.6	East Rambo Pond Inlet	115.0	36.7	47%
Q1	642.6	East Rambo Pond Box Culvert Outlet	18.8	1.6	9%
Q2	642.6	East Rambo Pond Spill at CNR	44.5	23.4	111%
Q3	642.6	East Rambo Pond Spill at North Service Road	8.0	8.0	NA
J1	718.0	East Rambo Creek at CNR	33.4	12.2	58%
J	736.5	East Rambo Creek at H-R Diversion Channel Conf.	38.7	13.2	52%
P	84.1	West Rambo Creek at QEW	27.7	9.1	49%
P3	116.7	West Rambo at CNR (South of Plains Road East)	65.9	35.8	119%
P2	130.6	West Rambo at CNR (North of DePauls Lane)	67.6	36.7	119%
P1	140.9	West Rambo Creek at Fairview	68.2	37.0	119%
K	886.4	H-R Diversion Channel D/S of West Rambo Creek	97.4	43.8	82%
L	952.4	H-R Diversion Channel U/S of West Hager Conf.	106.8	48.0	82%
G	661.6	Freeman Pond Inlet	127.4	50.0	65%
G1	661.6	Freeman Pond Outlet	20.5	3.1	18%
H1	155.0	West Hager Pond Inflow	27.2	9.1	50%
H2	155.0	West Hager Pond Outflow	13.7	2.4	21%
H	916.0	Freeman / West Hager Conf.	42.7	9.5	29%
M	1,868.4	West Hager / H-R Diversion Channel Conf.	138.2	46.6	51%
N	1,897.1	H-R Diversion Channel at Indian Creek	137.4	45.9	50%

Table 4.19 Simulated Peak Flows for Hager-Rambo Watershed – Sensitivity Analysis (Updated FCF Rating Curves)					
Node	Current Drainage Area (ha)	Location	Simulated Peak Flow (m^3/s)		
			Adjusted 100-Year Storm	Difference from Base IDF	Difference (%)
Q	642.6	East Rambo Pond Inlet	115.0	36.7	47%
Q1	642.6	East Rambo Pond Box Culvert Outlet	19.0	1.8	10%
Q2	642.6	East Rambo Pond Spill at CNR	47.1	24.7	110%
Q3	642.6	East Rambo Pond Spill at North Service Road	3.2	3.2	NA
J1	718.0	East Rambo Creek at CNR	33.4	12.2	58%
J	736.5	East Rambo Creek at H-R Diversion Channel Conf.	38.7	13.2	52%
P	84.1	West Rambo Creek at QEW	27.7	9.1	49%
P3	116.7	West Rambo at CNR (South of Plains Road East)	67.9	36.1	114%
P2	130.6	West Rambo at CNR (North of DePauls Lane)	69.5	36.7	112%
P1	140.9	West Rambo Creek at Fairview	70.0	36.8	111%
K	886.4	H-R Diversion Channel D/S of West Rambo Creek	98.4	42.8	77%
L	952.4	H-R Diversion Channel U/S of West Hager Conf.	107.8	46.8	77%
G	661.6	Freeman Pond Inlet	127.4	50.0	65%
G1	661.6	Freeman Pond Outlet	21.1	2.9	16%
H1	155.0	West Hager Pond Inflow	27.2	9.1	50%
H2	155.0	West Hager Pond Outflow	12.7	2.6	26%
H	916.0	Freeman / West Hager Conf.	42.0	11.8	39%
M	1,868.4	West Hager / H-R Diversion Channel Conf.	119.6	30.4	34%
N	1,897.1	H-R Diversion Channel at Indian Creek	120.6	31.0	35%

Similar trends are evident in the simulated results for both FCF rating curve versions of the modelling. The 35% increase in rainfall generally translates to peak flow increases greater than 35%, although the results vary by location. The majority of the nodes upstream of the three (3) FCFs all indicates increases such that the climate-changed adjusted 100-year event would generate a greater peak flow than the Regional Storm Event. Nodes downstream of these locations (i.e. along Hager Creek downstream of the Freeman and West Hager FCFs, and along the Hager-Rambo Diversion Channel downstream of its confluence with Hager Creek) indicate peak flows that are still below the Regional Storm, potentially due to the flashier/peakier nature of the 100-year storm event compared to the Regional Storm, which becomes more muted in larger drainage areas when the effects of routing are included.

Of some note is the difference in simulation results between the modelling with the "existing" (i.e. 2018) and "updated" (i.e. current study) at the most downstream limits of the model. The "updated" (current) rating curve model generates notably lower peak flows at the most downstream nodes (M and N along the Hager-Rambo Diversion Channel). This potentially reflects the cumulative effects of routing and attenuation and differences between the two versions.

FCF peak inflows are generally increased by 50% +/-; the resulting increase in peak outflow varies depending on the characteristics of the FCF in question. Simulated modelling results for each of the three (3) flood control facilities are presented in Tables 4.20, 4.21 and 4.22 for the East Rambo, Freeman and West Hager FCFs respectively.

Table 4.20	Sensitivity Analysis of Simulated Performance of East Rambo FCF for 100-Year Storm					
Metric	Original FCF RC			Updated FCF RC		
	Base IDF	Increased IDF	Difference	Base IDF	Increased IDF	Difference
Peak Operating Level (m – 1978 Datum)	106.13	106.52	0.39	106.11	106.56	0.45
Peak Storage (m^3)	156,900	192,100	35,200	153,400	191,200	37,800
Total Outflow (m^3/s)	38.3	71.2	32.9	39.6	69.3	29.7
Discharge via Primary Outlet (m^3/s)	17.2	18.8	1.6	17.2	19.0	1.8
Spill Flow (m^3/s)	21.1 (CNR) 0.0 (NSR)	44.5 (CNR) 8.0 (NSR)	23.4 (CNR) 8.0 (NSR)	22.4 (CNR) 0 (NSR)	47.1 (CNR) 3.2 (NSR)	24.7 (CNR) 3.2 (NSR)

Table 4.21	Sensitivity Analysis of Simulated Performance of Freeman FCF for 100-Year Storm					
Metric	Original FCF RC			Updated FCF RC		
	Base IDF	Increased IDF	Difference	Increased IDF	Base IDF	Difference
Peak Operating Level (m – 1978 Datum)	103.16	104.63	1.47	102.97	104.45	1.48
Peak Storage (m^3)	146,800	268,100	121,300	140,000	260,100	120,100
Total Outflow (m^3/s)	17.4	20.5	3.1	18.2	21.1	2.9
Discharge via Primary Outlet (m^3/s)	17.4	20.5	3.1	18.2	21.1	2.9
Spill Flow (m^3/s)	0	0	0	0	0	0

Table 4.22	Sensitivity Analysis of Simulated Performance of West Hager FCF for 100-Year Storm					
Metric	Original FCF RC			Updated FCF RC		
	Base IDF	Increased IDF	Difference	Increased IDF	Base IDF	Difference
Peak Operating Level (m – 1978 Datum))	NA	NA	NA	113.51	115.38	1.87
Peak Storage (m^3)	12,370	26,930	14,560	11,900	28,660	16,760
Total Outflow (m^3/s)	11.3	13.7	2.4	10.1	12.7	2.6
Discharge via Primary Outlet (m^3/s)	11.3	13.7	2.4	10.1	12.7	2.6
Spill Flow (m^3/s)	0	0	0	0	0	0

East Rambo FCF

The East Rambo FCF exhibits the greatest sensitivity to the simulated increase in rainfall associated with climate change. Peak inflows would be increased by approximately 50% due to the simulated 35% increase in rainfall. Peak discharges are increased by a correspondingly greater amount, given the free spill flow that occurs once FCF operating levels reach the level of the CNR QEW underpass. As evident from Table 4.17, simulated spill flows approximately double due to the simulated 35% increase in rainfall, given the free spill flow and the consumption of available storage volume due to the earlier portions of the storm event. The increased inflows also result in spill flow over the North Service Road under both rating curve scenarios, which was not indicated under the base (non climate change-adjusted) rainfall IDF scenarios.

Freeman FCF

The Freeman FCF receives a notably increased peak flow under the climate change altered rainfall scenario, with the peak flow increasing by 65% in response to the increase of 35% in the input rainfall. The Freeman FCF indicates a large increase in depth (1.48 m approximately) and volumes (approximately doubling). Notwithstanding, both rating curve scenarios indicate that despite the large increase in depth and volume the FCF does not spill via the overflow spillway, although elevations are close to spill height. The climate change adjusted rainfall discharges are still less than those under the Regional Storm Event, given the correspondingly larger rainfall depth/volume in that case as compared to the adjusted 100-year storm.

West Hager FCF

The West Hager FCF would be expected to experience much greater impoundment depths and volumes under the climate change altered rainfall scenario, with storage volumes more than doubling under this scenario, in response to an approximately 50% increase in peak inflow. This reflects the relatively consistent outflow capacity of the FCF until the spill (overflow berm) elevation is reached. As such, peak outflows would increase by a more modest amount, between 21 and 26% depending on the rating curve scenario in question. No spill would occur under either updated 100-year flow scenario. Overall, the West Hager FCF is generally insensitive to potential changes in rainfall associated with climate change, given its large available storage volume and associated depth.

4.4.3 Hydraulic Simulation Results

The hydraulic modelling approach discussed in Section 4.3.4 for the assessment of the expected overall changes with and without crediting of the three (3) FCFs has been applied in the current section for the analysis of the potential impacts of climate change. Specifically, the expected overall changes in flood depths and floodplain extents (top width) for the 100-year storm event (Original FCF Rating Curves Credited) with and without climate change adjustments. The updated hydraulic summary under the climate change altered rainfall scenario is presented in Table 4.23. The resulting differences between these results and the original (unaltered) 100-year storm event (as per Table 4.10) are presented in Table 4.24.

Table 4.23	Summarized Hydraulic Modelling (HEC-RAS) Results for Climate Change Adjusted 100-Year Storm Event with FCF Credited (Original Rating Curves)						
Reach	Length (m)	Depth (m)			Top Width (m)		
		Min	Max	Mean	Min	Max	Mean
East Rambo Creek	1,495	1.78	4.64	2.97	6.95	1,098.34	98.87
West Rambo Creek	575	2.28	5.35	3.73	6.46	434.55	135.47
Upper Hager-Rambo Diversion Channel	740	2.62	5.16	3.99	10.77	87.56	31.12
Hager Creek	1,320	2.99	6.66	4.15	4.71	448.54	146.69
Lower Hager-Rambo Diversion Channel	845	2.97	4.40	3.61	11.99	89.72	28.18

Table 4.24	Difference in Summarized Hydraulic Modelling (HEC-RAS) Results due to Climate Change (100-Year Storm Event, FCF Credited – Original Rating Curves)						
Reach	Length (m)	Difference in Depth (m)			Difference in Top Width (m)		
		Min	Max	Mean	Min	Max	Mean
East Rambo Creek	1,495	+0.44	+1.66	+0.96	+0.88	+830.91	+67.84
West Rambo Creek	575	+0.77	+0.35	+0.78	+0.46	+10.87	+26.00
Upper Hager-Rambo Diversion Channel	740	+0.63	+1.62	+1.20	+0.60	+62.40	+14.30
Hager Creek	1,320	+0.83	+1.35	+0.90	+0.18	+38.52	+98.47
Lower Hager-Rambo Diversion Channel	845	+0.60	+1.05	+0.85	+1.34	+70.70	+12.52

The simulated results indicate that overall, the hydraulic modelling results are less sensitive to the impacts of climate change than to the removal (or non-crediting) of the three (3) FCFs, as was presented previously in Table 4.12. Overall increases in simulated average depth range from 0.35 to 1.66 m (as compared to 0.38 to 2.06 m in Table 4.12). Similarly, average increases in top width range from 14 to 98 m (as compared to 21 to 172 m in Table 4.12). All of the subject watercourse reaches display a similar degree of sensitivity to climate change impacts, which may reflect the uniform impact of the adjusted rainfall data.

5.0 Remedial Works and Future Studies

5.1 Remedial Works

Based on Wood's visual, functional, structural, and geotechnical assessment of the three (3) Flood Control Facilities (FCFs) no critical functional issues were evident; all three (3) FCFs appear to be generally in good working order. No significant issues or defects have been identified which would prevent the crediting of the flood control function of the 3 FCFs. Notwithstanding, the following items have been noted which warrant follow-up remedial works:

- East Rambo FCF
  - Erosion repair at mid-point inlet into pond, including topographic survey verification and mitigation of culvert scour and culvert perching
  - Repair to rip rap lining of inlet ditch from North Service Road
  - Removal of debris from outlet grate and structure
  - Consideration for a bathymetric survey of the pond to confirm sedimentation and vegetation accumulation and need for a potential clean-out
  - Consideration for a follow-up structural inspection of the East Rambo culvert outlet (not included in the current study due to access restrictions – this work may however have been completed separately by MTO)
- West Hager FCF
  - Remove sedimentation in outlet control culvert
  - Consideration for a follow-up structural inspection of the West Hager culvert outlet following clean-out (not included in the current study due to access restrictions)

It is recommended that the City of Burlington work with Conservation Halton as well as MTO Ontario Hydro and CNR (in the case of the East Rambo FCF) to determine an approach to the design, tendering and implementation of the preceding works to the satisfaction of all parties.

5.2 Future Studies

In addition to the preceding remedial works (capital construction and maintenance activities), further study and analysis may also be warranted. The following additional recommendations (all beyond the scope of the current study) are noted in this regard:

- The City of Burlington is currently collaborating with Conservation Halton on an updated Operations and Maintenance Manual and associated responsibilities for the three (3) FCF (including resolving FCF ownership and maintenance responsibilities); this document should continue to advance separately from the current report.
- The City of Burlington may wish to consider undertaking further field monitoring and data collection efforts to support hydrologic model calibration/validation, which will allow for a more informed estimate of flood risk. This could involve a focused installation around the three (3) FCFs, in order to confirm that simulated inflows are reasonable.
- The preceding field monitoring effort could potentially be combined with an overall hydrologic modelling update for the Hager-Rambo system in particular, which would re-assess land use coverage/imperviousness and support model calibration/validation, and also potentially migrate the model to a more current tool (i.e. from SWMHYMO to Visual OTTHYMO or HEC-HMS, among others).
- The results of the climate change sensitivity analysis have re-confirmed the vulnerability of the East Rambo FCF, particularly with respect to the increase in uncontrolled spill to West Rambo Creek via the

CNR underpass. As detailed in the separate retrofit feasibility assessment (Wood, December 2020 – a copy has been included in Appendix A), a retrofit to re-direct additional flows to the East Rambo Creek system is considered neither desirable nor technically feasible (or cost-effective). Likewise, measures to prevent spill flows via the CNR underpass were likewise considered infeasible. Notwithstanding, other measures may warrant further consideration including the incorporation of additional flood control storage areas, either in the vicinity of East Rambo FCF (i.e. to control and store spill flows), or further upstream (i.e. to reduce inflows to the East Rambo FCF and thus reduce associated spill flows). Additional measures along West Rambo Creek may also be warranted. Such an assessment is however beyond the scope of the current study. Given the urbanized nature of the existing watershed, available land and opportunities for such measures may however be limited.

- Conservation Halton (CH) has identified a number of technical analyses and follow-up assessments that have been recommended to be completed by the City of Burlington following the completion of the current study (which is intended to support the drafting of Official Plan policies). The follow-up analyses (referred to as "Phase 2") are generally outlined in CH's comments of July 25, 2019 (Dearlove-Bustamante – refer to Appendix B), however a definitive Terms of Reference is being developed collaboratively between the City and CH for formal approval related to the associated scope. The Phase 2 analyses are intended to provide a more resolute level of detail to support future site plan submissions, and also incorporate more current/resolute topographic data from CH/City, as well as any updated land use information from the City of Burlington. It is expected that the refined flood control facility storage-discharge rating curves developed as part of the current study will be implemented into the Phase 2 scope of work.

Respectfully submitted,

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